Commentary

THE MINUTE

C. T. R. WILSON died last November. He will be remembered for the elegance and brilliance of the Cloud Chamber which writes the tracks of atomic particles and brings the transmutation of matter before our eyes. The mechanism of the Cloud Chamber is demonstrated daily, high in the sky, by the vapour trails of aircraft. Only those things which can be apprehended by the senses are 'sensible' and, for the lay public at least, only the sensible is acceptable. It is not the logic of science which impresses the layman who is bemused by the sweep and range from the cosmic to the sub-atomic; as the old Scotsman said of Shakespeare, so of the scientist: 'He must hae been a wonderfu' man for he thocht on a lot o' things I wouldna hae thocht on'. The public is impressed by apparatus and frequently concludes that a gadget is an end in itself instead of a device to develop an idea. The enormous and the minute impress by their size. The Sputnik is awe-worthy like the transistor, the one because it sweeps the heavens, the other because it is the size of a match-head. The construction of successful gadgets to order requires great depth of understanding. More important, the range and validity of a series of experiments are defined by the experimental means.

The minute has an appeal of its own. Throughout the ages the expertize has been valued both aesthetically and because it has been taken to illustrate the highest form of craftsmanship. The miniatures of the Elizabethan, Hilliard, are valued as priceless paintings—which indeed they are—and also because of the micro-skill with which they were executed. Indeed the extreme has, from time to time, been cherished simply as a demonstration of skill; we all know of examples of the Lord's prayer and the 123rd Psalm so inscribed that good eyesight requires the help of a strong microscope. Recently serious attention has been given to the development of scientific instruments constructed on the smallest possible scale. In part this is because such micro-instruments have peculiar merits simply due to their size and in part certain techniques of construction invite such a development. For example, a miniature, portable radio is a convenience and transistors find an obvious application in hearing aids.

It is worth distinguishing two reasons for seeking miniatures. A large geometric arrangement may have obvious disadvantages. To measure the velocity of light over a base-line of several miles introduces complications of temperature and pressure, of refractive index, which are very difficult. In cases where space is at a premium, as in an aircraft or a sputnik, the benefits are obvious. The commercial, heavy-duty, small capacitors developed since the war have been of real advantage in aircraft and are worth far more than their weight in gold. In a sputnik, size dictates the number and nature of the experiments which can be performed on each voyage. Moreover certain investigations are simply impossible unless the apparatus is sufficiently small. For example* a radio transmitter has been developed in a small capsule which can be swallowed and which provides information on the temperature, pressure and pH of various parts of the intestine.

There are two obvious features which determine the degree of success. The more obvious one is the simple factor of scale. If all the dimensions of an instrument are reduced by a factor n, the consequent performance can be readily predicted. This is the basis of all model experiments such as those in wind tunnels, and an elementary and well established 'dimensional analysis' suffices in many cases to eliminate certain experimental methods. The second feature is the question of practical construction and technical specification. Can the reduction in size actually be achieved and does this alter the fundamental parameters which bear on the performance? In other words, is the physics or chemistry of the system modified by the reduction in scale? For instance, it is obviously impracticable to reduce the scale of thermionic vacuum valves below a certain, fairly well defined, limit. The principles governing the alternative transistor are different and, in recent years, intense activity has been devoted to extend the frequency response of transistors so that complex computers of the modest dimensions of office furniture are now possible. Furthermore the size of transistors is of little benefit if the other components of the electrical circuits, the capacitors for instance, must remain essentially unchanged. Miniatures impose their own technology and the hard problem of the economics of production can never be forgotten. The benefits of the techniques of printed circuits have to be set against the scale of actual and potential uses.

Microinstruments are perhaps associated in the public mind with missiles and satellites but they are of much wider interest. Space as well as time means money and new fields of study are opened up. These are some of the reasons why the first of a short series of articles on Microinstruments is published in this copy of *Research*.

* See *Medical Electronics*, p 78

MINIATURE GYROSCOPES

for Aircraft and Guided Missiles

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Gyroscopic instruments have many applications to the stabilization and navigational systems of airborne vehicles. The special requirements of guided missile control systems and recent developments in the design of aircraft autopilots have created a demand for miniaturized gyroscopes possessing high accuracy together with exceptional reliability and robustness. Some of the fundamental problems associated with the design of these miniature gyroscopes are discussed and typical examples of these instruments are described. This is the first of a series of articles on *Microinstruments*.

SINCE Foucault first applied the gyroscope over a century ago to his celebrated experiments directed towards demonstrating the rotation of the earth about its axis, this fascinating instrument has been found to have a multitude of practical applications —a high proportion of these in the field of aeronautics. The role of the gyroscope as a primary sensing element of the aircraft autopilot, or *George* as it was affectionately termed by the R.A.F., in world war II, is probably the best known example of its many aeronautical applications. More recently the remarkably rapid development of guided missiles and space vehicles would have been seriously impeded but for the application of the convenient properties of the gyroscope to the control and guidance systems of these vehicles. Indeed, as a result of the tremendous increase in aviation activities, a vast industry has sprung up to cater for the demand for these instruments and the systems in which they are used.

The advent of the guided missile created a demand for miniature components owing to the necessarily limited space usually available for control and guidance equipment within most of the smaller vehicles. As a result of experience gained in this field the designers of aircraft flight control systems have found many of these miniature components to be of great value in the development of lightweight autopilots of advanced design. The spectacular progress made in the development of miniature and sub-miniature electronic components for these purposes has been widely publicized but probably rather less is generally known of the corresponding development of miniature precision, electro-mechanical instruments.

It is the purpose of this account to consider in general terms some of the problems and techniques involved in the miniaturization of gyroscopes intended for use in aircraft or guided missiles and to review the progress made in this direction.

Basic Principles

It is not here intended to delve deeply into the theoretical principles of the gyroscope since this has been done adequately in a number of works of reference on the subject[1,2,3]. Nevertheless, if the implications of the design of miniature gyros are to be appreciated, some elementary knowledge of the mechanics of the gyroscope is necessary.

Essentially, the gyroscope consists of a freely suspended wheel spinning about its axle at a constant angular velocity. Such a device has two important properties, (*a*) its ability to maintain its plane of spin in space unless it is disturbed by externally applied torques and (*b*) its ability to precess or rotate about an axis mutually perpendicular to the axis of spin and the axis about which a torque is applied (*Figure 1*). This behaviour is consistent with the principle of the conservation of angular momentum, in which it is established that the total resolved angular momentum of a system of particles rotating about a given point remains constant irrespective of internal changes of configuration unless it is influenced by external forces.

It can be shown that the basic equation relating the above phenomena is

$$T = Jw\Omega,$$

where T is the applied torque, J the polar moment of inertia of the wheel, w the angular velocity of the wheel and Ω the precession rate. The direction

of precession of a gyroscope will depend upon the direction of the applied torque and of the spin of the gyro wheel (or rotor) about its axis as is shown in *Figure 1*. However, if the gyroscope is restrained in the precession axis, the direction of the torque developed about that axis will depend upon the direction in which the axis of spin is rotated and the direction of spin of the rotor about its axis.

From the above statements it is clear that there may be two basic configurations of the gyroscopic instrument, *i.e.* the ' free ' gyro and the ' restrained ' gyro.

In the free gyro, the rotor is pivotally supported by two gimbals and a frame so that the system has three degrees of freedom, including the spin axis. In this form, the gyroscope may detect and measure angular displacements of the frame (or carrying vehicle) in two axial directions from some given datum attitude or direction (*Figure 2*).

In the restrained gyro, the rotor is supported by a single gimbal which is pivotally connected to a frame but which is restrained in some manner about the pivotal axis. Assuming a linear restraint, *e.g.* a torsional spring, it can be shown that the angular deflection θ about the restrained precession axis is proportional to the angular velocity Ω applied about the input axis, which is mutually perpendicular to the precession axis and the spin axis, since

$$S\theta = Jw\Omega$$

where S is the torsion spring stiffness and θ the angular twist of spring (and gimbal), assumed to be very small. This form of gyroscope, which is known as the ' rate ' gyro, may therefore detect and measure the rate of change of angular displacement of the frame (or carrying vehicle) about the input axis. Some damping is incorporated in the gimbal

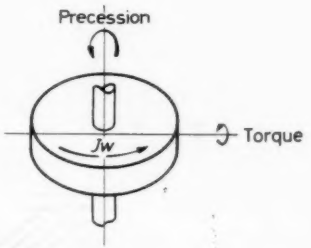


Figure 1. The direction of precession of a gyroscope

suspension so that spurious transient oscillations may be eliminated or, at least, minimized (see *Figure 3*).

Applications

A diverse range of gyroscopic instruments is currently used in both aircraft and guided missiles. In aircraft, these instruments may be considered

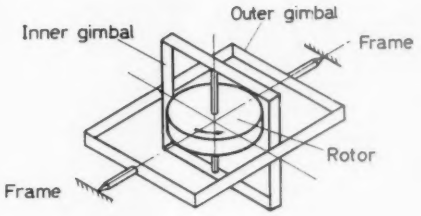


Figure 2. The free gyroscope

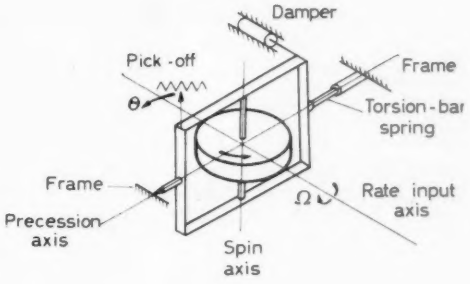


Figure 3. The rate gyroscope

under two main classifications, *i.e.* those which provide the pilot with visual indications of changes in aircraft attitude or direction relative to predetermined terrestrial data, and those which sense these changes but transmit the intelligence to some form of automatic pilot or navigational device. Both free and rate gyroscopes are used for these purposes. Free gyroscopes, suitably monitored by pendula and magnetic compass, provide continuous information on aircraft attitude and heading while rate gyros are used to detect rates of change of aircraft attitude or heading. It will be appreciated that indicating gyroscopic instruments such as the *Artificial Horizon* (or attitude indicator) are of considerable value to the pilot of an aircraft flying in poor visibility. Of no less value are the sensing gyros of the automatic pilot, the device which relieves the human pilot from much of the fatigue of a long flight, thus leaving him relatively fresh for the all important business of the landing approach and touch-down. Detailed information

on these instruments may be found in any one of a number of reference books on gyroscopes[4].

Clearly most of the gyroscopes used in guided missiles must be components of automatic control and guidance systems, although some may be used

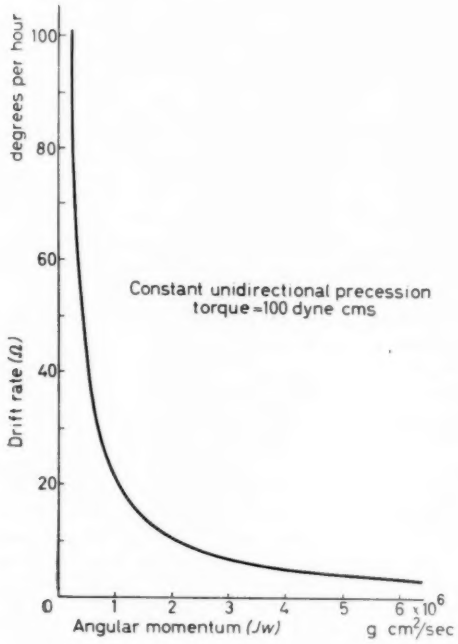


Figure 4. The influence upon drift rate of the angular momentum of a free gyroscope

for instrumentation purposes, *e.g.* to transmit telemetered data on vehicle stability or trajectory to ground monitoring stations. Again both free and rate gyros may be used although, except perhaps in the case of the longer range ballistic missiles, the free gyros usually provide only a relatively short term spatial reference rather than the longer term, terrestrially monitored reference necessary for most aircraft applications. Typically, command signals from the guidance system may be fed into the automatic pilot so that the missile is steered along a flight path determined by its guidance system to its target.

As is now generally known, the longer range ballistic missiles require very precise guidance systems, often called ' inertial navigators '. Described in the simplest terms, such a system commonly consists of a number of high precision linear accelerometers mounted upon a servoed platform which is stabilized spatially by high precision gyroscopes and which, with the aid of a suitable computing system, may from its own intelligence accurately guide a missile along a flight path, measured in thousands of miles, from its launching pad to its target. The gyroscopes commonly used in these applications are of extraordinary precision and have been the subject of a number of authoritative articles[5,6].

The launching and flight accelerations together with the severe structural vibrations associated with most rocket powered guided missiles demand that only especially rugged components and instruments be used. These conditions present special problems in the design of suitable gyroscopes since these components have in the past come under the category of ' delicate instruments—handle like eggs '.

Design Criteria

Some design criteria will now be established for the two basic types of gyroscopic instrument described above, *i.e.* the free and the rate gyro, giving special consideration to their respective miniaturization potentialities.

The Free Gyro

If the rotor spin axis of an ideal free gyroscope was to be aligned with some point in space, it would

Figure 5. A small vertical gyroscope

continue to point in that direction for as long as the rotor could be kept spinning at a constant speed. Unfortunately, such an ideal instrument has yet to be designed. All practical gyroscopic instruments

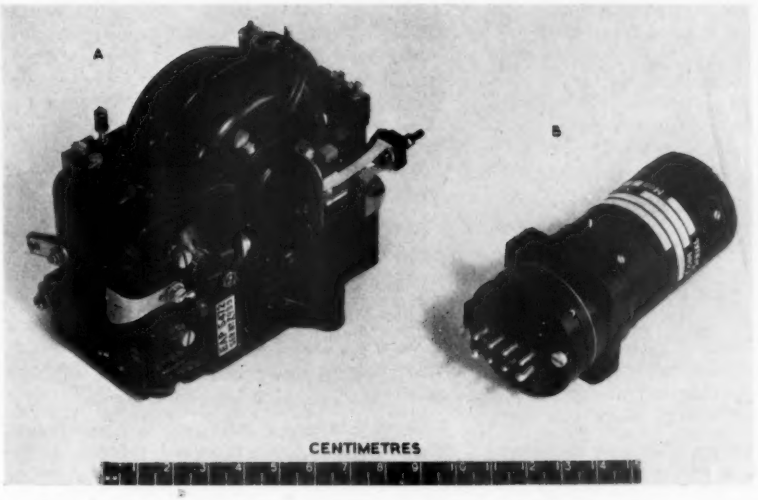


Figure 6. A—*A standard autopilot type rate gyroscope;*
B—*A miniature rate gyroscope for autopilot use*

suffer from imperfections which, however minute, introduce extraneous torques resulting in unwanted precession. This parasitic precession is usually known as the gyroscope's *free wander* or *drift* rate. If gyroscopic instruments are to provide accurate and reliable spatial, attitude or directional references, their drift rates must be kept to an absolute minimum and to this end designers and engineers have been striving for many years. The primary causes of drift of a simple free gyro are

(*a*) friction torques of the supporting gimbal bearings,

(*b*) mass unbalance of the gimbal system about the pivotal axes and

(*c*) other torsional restraints, *e.g.* electrical contacts or ligaments required to supply current to the electric motor driving the gyro rotor, *etc.*

The gyro equation, $T = Jw\Omega$, indicates that the effects of these imperfections may be minimized by ensuring that the angular momentum (Jw) of the rotor is as high as possible in any given size of instrument.

In a very small or miniature instrument, a high angular momentum can be achieved only by spinning the rotor at very high speed. Unfortunately in practical instruments there are factors, (*e.g.* lubrication), which limit the maximum speeds at which these rotors may be driven so that there must be some compromise between low gyroscopic drift and instrument size. The theoretical relationship between gyroscopic drift rate and angular momentum for a given value of uni-directional precession torque is shown in *Figure 4*, the values used to construct this curve being representative of gyro instrument designs. Since drift rates of less than 15 degrees per hour are expected of nearly all conventional, aircraft and missile free gyroscopes and since the value of the precession torque assumed in *Figure 4* is equivalent to the friction torque of the very highest quality miniature precision gimbal ball bearings available, there is clearly a practical limit to the possible degree of miniaturization of this class of gyroscope. Miniaturization is limited further by the fact that position pick-offs, *e.g.* potentiometers, and perhaps monitoring precession torque motors *etc.*, have also to be accommodated if the instrument is to serve any useful purpose.

While relatively low grade (60–180 degrees per hour) sub-miniature free gyros have been used to provide short term references in various missile flight control systems, high precision miniature rate gyroscopes are now more commonly used in these applications because of their inherent simplicity, greater robustness and even smaller size. Where the drift rate permits, angular position data may be obtained from the rate gyro by integrating the rate signal electronically.

The Rate Gyro

As has already been explained, the function of the rate gyro is to detect and measure angular velocities

applied to it about its sensitive axis and to transmit this intelligence to some form of display or control system. An ideal rate gyro would do precisely this, but all practical instruments inevitably contain minute imperfections which tend to modify slightly this function in various undesirable ways. A brief design analysis of a typical rate gyroscope may conveniently serve to illustrate some of these shortcomings and their causes.

A typical modern instrument comprises an electrically driven high speed rotor in a gimbal which is, in turn, attached to a frame *via* a damped torsional spring suspension located in the precession axis (*Figure 3*). In addition a position pick-off, *e.g.* a differential transformer, is located in the precession axis so that it may generate electrical signals corresponding with angular velocities applied about the sensitive axis of the rate gyro.

The performance of such an instrument is subject to various errors of which the following are among the most important: (*a*) zero errors, (*b*) hysteresis, (*c*) slope errors, and (*d*) threshold insensitivity.

A zero error exists if the pick-off signal is not zero (or some other specified value) when the rate gyro experiences zero angular velocity about its sensitive axis. Zero errors may result from thermal differential expansion of components within the instrument, built-in mechanical stresses, induced mechanical stresses, variations in electrical power supplies and various other imperfections particular to specific designs.

Hysteresis errors result from the inability of the torsion spring system to respond precisely to variations in the precession torque applied. All spring materials exhibit some mechanical hysteresis which usually increases as the stress applied. Hysteresis errors add to zero errors and cause non-linearities.

Slope errors, *i.e.* variations in signal strength per unit angular velocity, usually result from variations in gyro angular momentum (rotor speed) or variations in pick-off excitation level.

Threshold insensitivity is the inability of the rate gyro to produce sensible signals corresponding to very small angular velocity inputs below some specified low level. This type of error, usually due to friction, particularly applies to rate gyros which are fitted with gimbal bearings in addition to a torsion spring in the precession axis.

Where a rate gyro is a component in a servo system, an additional problem is posed in that, ideally, the dynamic response of the instrument should be a known constant. In practice this is not simple to achieve owing mainly to the difficulty of providing the gimbal system with damping which is entirely unaffected by temperature or other variable environmental conditions.

In spite of these and certain other limitations to its accuracy, the rate gyro lends itself more favourably to miniaturization than does the free gyro. The fundamental reason for this is that whereas, when all other variables are assumed constant, the drift rate of a small free gyro is substantially

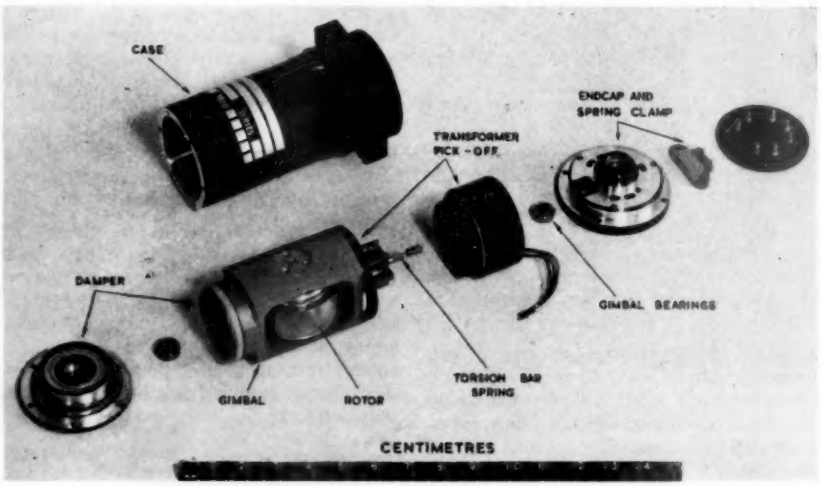
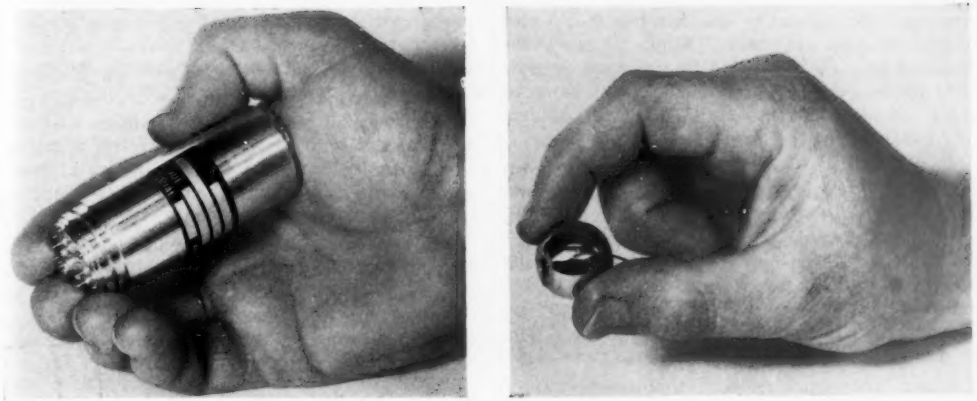


Figure 7. Components of a miniature rate gyroscope



(*a*) *A sub-miniature rate gyroscope* (*b*) *A sub-miniature gyro rotor*

Figure 8

dependent upon its angular momentum (*Figure 4*), the drift rate (or zero error) and general accuracy of a simple rate gyro are substantially independent of its angular momentum but are dependent only upon its measuring range of angular velocity for a constant maximum gimbal deflection θ_{max}.

Typical Instrument Designs

It is probably true to say that there are almost as many different designs of gyroscopic instruments as there are applications for them. However in this relatively short account it is only possible to describe a few of the more widely used types and especially those which have been miniaturized with some degree of success.

While miniaturization of the free gyroscope has been shown to have practical limitations, nevertheless, with the development of improved instrument manufacturing equipment and techniques, progress has been made in this direction in recent years.

A typical example of a small free gyroscope suitable for use as an aircraft autopilot component is shown in *Figure 5*. This instrument is a small electrically operated vertical gyroscope, *i.e.* a free gyro which is monitored internally by a gravity sensitive erection system so that its spin axis is kept vertical whatever the angular movements of the frame within the limits of freedom of the two gimbals. The rotor is driven at 24,000 rev/min by an internally fitted synchronous electric motor, its axis being kept vertical to within a few minutes of arc by electrical type torque generators situated in each gimbal axis which are controlled by gravity sensitive switches mounted on the rotor casing. Gimbal movements are detected by signal generators, commonly of the synchro type. The drift rate of the instrument of less than 15° per hour is necessary in order that the monitoring erection rates may be kept low enough to avoid serious erection errors which are possible during accelerated flight, *e.g.* during a take-off when the gyroscope will tend to erect to the apparent vertical as sensed by the pitch axis gravity sensitive erection switch.

As an indication of the precision required in the manufacture of such a gyroscope, it can be shown that a displacement of 2 microns of the centre of gravity of the rotor out of coincidence with the gimbal axes would produce a drift rate of about 10° per hour. The weight of the instrument shown in *Figure 5* is about 1·7 kg which is about half the weight of earlier designs having similar performance.

Perhaps more impressive is the progress which has been made in the development of miniature precision rate gyroscopes. As an example, *Figure 6* compares the size and style of a widely used aircraft autopilot rate gyro (A) with that of its more modern counterpart, a typical miniature rate gyro (B). The latter, weighing only about 250 g, has approximately one quarter of the weight and volume of the former but yet it has, in certain respects, the superior performance of the two instruments. The separate components of this miniature rate gyro are shown in *Figure 7*. It should be explained that the rotor is driven internally by a high speed synchronous electric motor and that the gimbal damper is of the fluid filled type, suitably temperature compensated. Such an instrument can be adapted to measure angular velocities ranging from less than one-tenth of a milliradian per second to at least ten radians per second, simply by interchanging torsion bars. By careful design and manufacture, zero and hysteresis

errors may be reduced to less than one thousandth part of the measuring range. Miniature rate gyros of this kind have proved to be extremely rugged; even while operating under extreme conditions of shock, vibration and acceleration, they will continue to give satisfactory performance.

An example of an even smaller gyroscope is shown in *Figure 8a*. This is a typical sub-miniature rate gyro weighing just over 100 g and designed to match, as nearly as possible, the performance of the larger instruments. As an indication of the scale of the components used in these tiny instruments, a typical sub-miniature gyro rotor is shown in *Figure 8b*. This rotor is driven by a high speed hysteresis type electric motor which is enclosed by the rotor shell.

Airline economics demand that most modern aircraft gyroscopes give satisfactory service without attention over a period of at least 3000 hours, *i.e.* equivalent to the period covering about three engine changes of many motor cars. The problem of meeting this requirement tends to become more difficult as the size of the instrument decreases owing to the greater influence of dimensional errors and contamination of components upon long term performance; thus extreme precautions have to be taken during all miniature gyroscope manufacturing operations to ensure that very high standards of dimensional accuracy and cleanliness are maintained.

Gyroscopes for Inertial Navigation Purposes

The gyroscopes used in inertial navigation systems are extremely precise and expensive versions of the free gyroscope and the rate gyroscope, although they are of somewhat different configurations, in order to achieve the very high performance demanded of them, *e.g.* absolute drift rates of less than two degrees per hour with standard deviations of less than one-tenth of a degree per hour.

The so-called Rate Integrating Gyroscope, which was originally developed by the Massachusetts Institute of Technology, is probably the most widely used type. This instrument resembles the simple electrically operated rate gyro except that the gimbal restraint takes the form of viscous drag instead of a spring, so that the output angle θ is, in this case, proportional to the time integral of the input rate Ω. The fluid producing the viscous drag also supports the float-like gimbal so that gimbal pivot friction is virtually eliminated. A torque generator located in the output axis is used either for monitoring purposes or as an ' electrical spring ' depending upon whether the instrument is to be used as a single axis displacement gyro or as a super-precision rate gyro.

These instruments are usually mounted upon the servoed platforms which they stabilize, and they are provided with very closely controlled operating conditions, *e.g.* precision electrical power supplies, ambient temperature control *etc.*, in order that they may function satisfactorily.

Instruments of this type have also been successfully miniaturized in recent years, *e.g.* weights have been reduced from 3 kg to 250 g, but the cost of these components increases considerably as the size decreases owing to the extraordinary precision required in their manufacture.

Future Development

Although the development of the gyroscopic instrument has clearly reached an advanced stage, much has still to be done in order to satisfy completely all of the ideal requirements ranging from those of the airline operator to those of the missile designer. For example, one of the ultimate aims is to produce relatively inexpensive precision gyroscopes of sub-miniature proportions and of high performance, *i.e.* having absolute drift rates of less than one-tenth of a degree per hour even while operating under a wide range of unfavourable environmental conditions and being guaranteed for at least 10,000 hours of continuous, reliable operation. At present it appears unlikely that such a specification can be met by using conventional techniques so that there is still much scope for the gyro designer.

Not all applications need gyroscopes of such a high precision grade but even the designs of the lower grade instruments deserve further attention with a view to reducing their cost without detriment to performance and to extending further their operational life and reliability.

Acknowledgment is made to Smiths Aircraft Instruments Limited for permission to publish this paper, including the photographs.

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CRYOTRONS AND OTHER SUPERCONDUCTING COMPUTER DEVICES

Recent Advances

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The non-linear properties of superconductors led to the invention, in 1955, of the Cryotron, and since that date considerable progress has been made towards the improvement of this and other superconducting computer devices. One of the most promising new developments is the information storage element known as the Crowe cell. This is capable of switching in 10 millimicroseconds, 100 times faster than the conventional ferrite core

A GREAT simplification is achieved in modern computers by carrying out all the really high speed operations in binary code, so that both numbers and logical instructions are represented by sequences of noughts and ones only. As a result the basic building bricks used in the construction of these machines can be physical devices whose essential property is that they possess just two stable states.

Consider, for example, the relay, which has open and closed states, and the ferrite core, whose states are those of remanent magnetization in two opposite directions. These devices are, incidentally, typical of the two most important parts of a large computer —namely, the logical circuitry and the 'memory' or information store respectively. In the first of these, arithmetical and logical operations are carried out on the numbers presented to it, and such operations, which entail gating and switching of electrical pulses, are most conveniently carried out by a device like the relay, whose essential feature is that, by means of a small controlling current, it can direct a comparatively large amount of power to the appropriate place. Such a device is usually called 'active'. In the memory, on the other hand, we only need to store the numbers resulting from the various intermediate stages of a calculation, and for this purpose a purely passive device, like the ferrite core, is all that is required. The other most important property of a useful computer device is the ability to switch rapidly from one state to the other, a feature which the mechanical relay does not, of course, possess.

What then are the properties of superconductors which enable them to be used in two-state devices? Their most striking feature is, of course, that at some very low temperature, usually a few degrees Kelvin, their resistance suddenly drops to zero. Below the transition temperature, however—and this is the important point—the normal resistance of the superconductor can still be restored by subjecting it to a magnetic field greater than a certain critical value, H_c, depending on the temperature. A typical critical field curve, that of pure tin, is shown in *Figure 1*.

Now, because electric currents give rise to magnetic fields, it follows that a large enough current in a superconducting wire can itself restore resistance in it, so that we can speak of the critical current of the wire. Except for exceedingly thin wires and films, of the order of 10^{-5} cm in linear dimensions, it is in fact just that current which will produce the critical field at the surface of the wire.

The electrical resistance of a superconductor is thus a non-linear function either of the applied magnetic field or of the current through it, remaining zero up to some critical field or current, and then rising to its full normal value at higher fields or currents. It is this non-linearity of resistance which is used in the construction of bistable superconducting devices.

The Cryotron

The first such device to appear was the *Cryotron*, invented by Dr BUCK of the Lincoln Laboratory, M.I.T., in 1955[1]. This consists simply of a superconducting solenoid wound on a central superconducting gate wire, whose resistance can thus be controlled by the current in the solenoid (see *Figure 2*). The gate wire is made of tantalum ($T_c = 4{\cdot}4$°K) about one hundredth of an inch in diameter, and the solenoid, or control winding, of niobium wire ($T_c = 8$°K) of diameter about one three hundredth of an inch. The sizes are chosen so that the critical field of the tantalum gate at the temperature of the liquid helium bath (4·2°K), which is about 40 oersteds, can be produced by a current in

the solenoid of about 300 mA, much too small to drive the niobium wire itself normal, and in fact the control winding remains completely superconducting under all operating conditions.

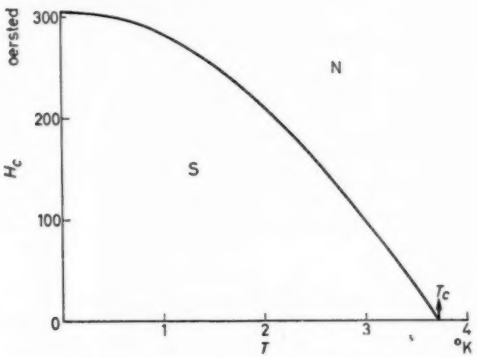

Figure 1. Critical field curve of pure tin

The important feature of the cryotron is that the gate current of one cryotron can be used to control a second identical one, provided that the critical current of the gate wire is greater than the control current required in the solenoid. Since the gate current produces a field

$$H_g = 2i_g/r$$

at the surface of the gate wire, where r is its radius, and the solenoid current a field

$$H_s = 4\pi n i_s$$

where n is the number of turns per cm, this condition reduces to $2\pi nr > 1$. The quantity $2\pi nr$, denoted by K, is called the *current gain* of the cryotron, and for the dimensions shown in *Figure 2* is about 7. Provided that K is greater than unity, cryotrons can be used to control one another in logical circuits without the use of additional amplifying devices. They are, like relays, 'active' circuit elements.

The simplest such circuit consists of two cryotrons connected in parallel with the gate of one in series with the solenoid of the other, and behaves as a bistable element or flip-flop. Thus an externally supplied current can flow either through gate A and solenoid B, keeping gate B resistive, or through gate B and solenoid A, keeping gate A resistive (see *Figure 3*). We need more than this, however, to make a workable flip-flop. Two further control cryotrons, C and D, are required to switch the current from one path to the other ('write' 1 or 2), and at least one more, E, to sense (or 'read') the state of the flip-flop (*Figure 4*). It is important to notice that a *constant* current is supplied externally to the flip-flop, and it is the *path* that this current takes which can be switched by means of current pulses supplied to the control cryotrons.

How quickly can this switching process be accomplished? It turns out that there are two main factors involved. In the first place, the rate at which the current in one path decays when resistance is introduced in it by means of the appropriate control cryotron, and builds up in the other path, is determined by the self-inductance, L, of the control windings, and by the normal resistance, R, of the gate wires, and it turns out that the complete switching process takes about $7L/R$. Even with the small size of the actual cryotron this time is about 150 μsec, so that the wire-wound cryotron can scarcely be called a fast device as modern computers go. For example, the best ferrite cores can be switched in about 1 μsec, and a good transistor flip-flop perhaps ten times faster.

A second limitation to the speed of this type of cryotron is due to the heating which occurs in the gate of one element, when its resistance has just been restored by the 'write-in' pulse, but while the current in it has not yet died away. The rate of heating is Ri^2 and it lasts for a time of the order of L/R, so that the total heat dissipated is about Li_0^2, where i_0 is the current initially flowing in that arm of the flip-flop. Warming of the gate wire occurs, and it is found in practice that, because the maximum permissible temperature rise of the tantalum is only about 0·1°K, this limits the switching frequency of the flip-flop for repetitive working to only about 1000 c/s.

The Strip Cryotron

Now that we have seen why the wire-wound cryotron is rather slow in operation, it is natural to ask what can be done to improve its performance. Since we want to make L smaller and R larger, one possibility is to use thin evaporated films of superconductor instead of relatively thick wires. This results

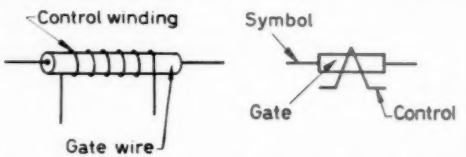

Figure 2. The cryotron. The control winding consists of 250 turns of 0·003 in. diameter Nb wire. The gate wire is 1 in. long 0·009 in. diameter Ta wire. (Reproduced by courtesy of Engineering (1959) 187, 550)

in the 'strip cryotron', which has been tested with some measure of success at the I.B.M. laboratories in America, and in which the basic circuit consists simply of two evaporated superconducting strips

crossing one another at right angles, and insulated from each other by an intervening evaporated film of silicon monoxide (see *Figure 5*). The gate strip is of tin (T_c=3·73°K), and the control strip of lead (T_c=7·2°K), and the magnetic field produced by a current in the latter can restore resistance in the narrow area of the gate directly under it. The lead ground plane shown in the figure serves an important purpose. It acts as the return path for both the gate current and the control current, and by confining their magnetic field to the narrow region between the strip and the plane it greatly reduces the self-inductance of each circuit (a value of 10^{-11} H per cm length of control strip is claimed). For the same reason it makes the current distribution in the gate strip more uniform and thus raises the critical current of the gate. This is of vital importance, since the chief difficulty with the strip cryotron seems to be the avoidance of structural imperfections in the evaporated films which lead to a severe reduction of the critical current of the gate strip, and thus to a lowering of the current gain. Using the utmost care in the evaporation conditions, and with the dimensions shown in *Figure 5*, a maximum current gain of 4 has been reported[2], whereas the theoretical value for the indicated ratio of gate to control strip width should be about 30.

Figures for the high speed performance of this type of cryotron are not yet available, but it is possible to estimate a rough value of the L/R constant of a flip-flop of about 10^{-8} sec. It should certainly be many orders of magnitude faster than the wire-wound cryotron.

Figure 3. The flip-flop. (*Reproduced by courtesy of Engineering* (*1959*) **187,** *550*)

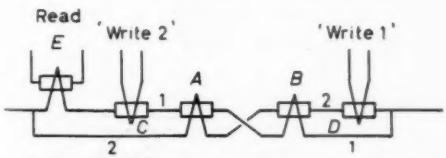

Figure 4. Complete flip-flop. (*Reproduced by courtesy of Engineering* (*1959*) **187,** *550*)

The Crowe Element

A second type of superconducting device based on a somewhat different principle will now be described, which acts as a passive information storage element only, and not as an active element like the cryotron. It makes use of the possibility of setting up persistent currents in a superconducting circuit, and using their direction to represent the two states required for information storage. Such a current, once set up,

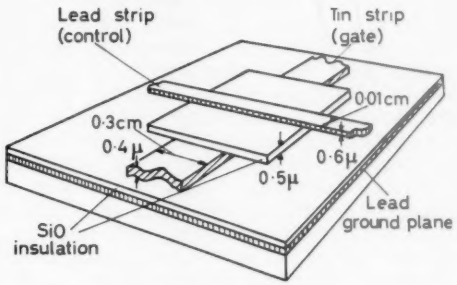

Figure 5. The strip cryotron

will flow indefinitely as long as the circuit remains below its transition temperature, and so can be used as a 'memory', just as we use the remanent magnetization of a ferrite core. This device was invented by J. W. Crowe[3] in 1957, and has now been studied in some detail both at I.B.M. in America, and in this country at the Royal Radar Establishment and at the Services Electronics Research Establishment.

Figure 6a shows the construction of the Crowe element, the important feature being the crossbar which bridges the circular gap in the evaporated film of superconductor, leaving two D-shaped holes in the circuit on either side. The two states of the device are represented by persistent currents in the film, flowing in the directions shown in *Figures 6b* and *6c*. These states are set up by passing an appropriate pulse of current through the drive wire, which is closely linked inductively with the crossbar, and changes of state are detected by the pick-up wire beneath it. The whole operation of the element depends on the restoration of resistance in the crossbar when the current in it reaches its critical value. This critical current's value depends on the width and thickness of the crossbar and on the temperature of the surrounding helium bath, and for a tin film 2000 Å thick and 0·2 mm in width it reaches a value of about ½ Amp when the film is well below its transition temperature. These dimensions are typical of the elements studied at the Royal Radar Establishment, a set of three of which are shown in *Figure 7*. Here the drive wire, a silver strip evaporated on a separate sheet of mica, is shown raised to enable the underlying tin elements to be seen. It is worth reiterating the fact that,

whereas the cryotron uses the restoration of resistance in a superconductor by an external magnetic field, the Crowe element uses the current in the superconducting circuit itself to restore its resistance.

Let us now consider the behaviour of the device in slightly greater detail. The drive wire and the superconducting circuit can be regarded as the primary and secondary respectively of a single turn transformer. Now the resistance of the secondary is normally zero, and as long as this is the case there can be no change in the flux linking it; whenever the primary current changes, an equal and opposite change of current is induced in the secondary keeping the flux through it constant. It also follows that under these circumstances there can be no e.m.f. induced in the pick-up wire beneath the crossbar—the superconducting film screens it perfectly from the drive wire. But whenever the secondary current reaches its critical value in the crossbar, resistance is restored in the circuit and the current in it drops rapidly. At the same time the flux linked with it also changes, and a voltage pulse is induced in the pick-up wire. We are now in a position to understand the schematic mode of operation of the

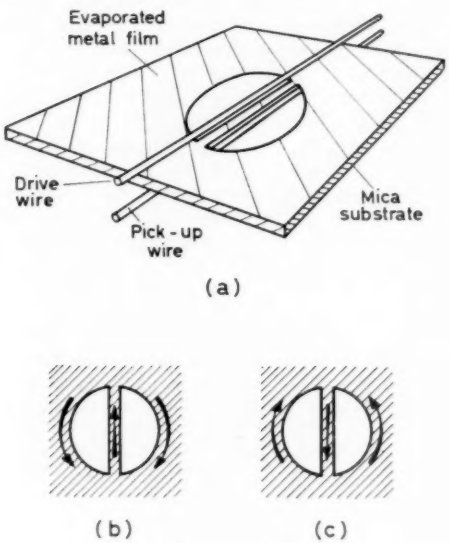

Figure 6. The Crowe element. (Reproduced by courtesy of Engineering (1959) 187, 550)

element shown in *Figure 8*, in which drive current, crossbar current and pick-up voltage are plotted against time. Starting with zero current in the circuit, a large enough positive drive pulse first induces an equal and opposite current in the superconducting crossbar, and then when it reaches the critical value a sharp drop in the crossbar current occurs. On the trailing edge of the drive pulse, when the secondary circuit is once more entirely superconducting, the change in the crossbar current thus leaves a positive persistent current flowing in the element when the drive current has fallen to zero. This current is taken here to represent the '0' state of the element. The second drive pulse of opposite polarity clearly leaves a negative persistent current flowing, so that the element has been switched to the '1' state, while the third pulse switches it back to the '0' state. If, however, two (or more) successive pulses have the same polarity, such as the third and fourth in *Figure 8*, during the second of these the crossbar current never reaches its critical value, so that no switching takes place and the element remains in its original state.

We may summarize the behaviour of the Crowe element so far in the following way. 'Interrogation' or 'reading' of the element implies the application of a 'write 0' pulse. If it is storing a '1', it will then switch to the '0' state, and a voltage signal will be induced on the pick-up wire, as shown below the third pulse in *Figure 8*. If it is already in the '0' state it will remain so, and no voltage signal will be observed, as shown in the case of the fourth pulse. After interrogation the element will thus always be in the '0' state, so that the reading process is said to be destructive, and the information, if required again, must be rewritten into the memory. This is the method commonly used with the ferrite core store, and presents no special difficulties.

It is not difficult to see that if the amplitudes are suitably chosen, then half-level pulses, positive or negative, will not disturb the state of the element. This is shown by the fifth pulse in *Figure 8*, a 'half-write' pulse. Thus coincident current working, using two drive wires for each element, can be used for selection of elements in a square array. This is clearly a most important facility for the construction of a really large computer store using these elements.

Switching Speed

Two factors govern the speed of the Crowe element. One is the L/R constant of the circuit when the crossbar is driven resistive, since this controls the rate at which the crossbar current falls to its new value at the end of the rising edge of the drive pulse. The tin elements shown in *Figure 7* have a self-inductance of about 10^{-9} H and an effective normal resistance of about 0·1 ohm, so that L/R is about 10^{-8} sec. In the second place during this resistive

phase of the cycle the temperature of the crossbar rises owing to the Joule heat developed in it, and

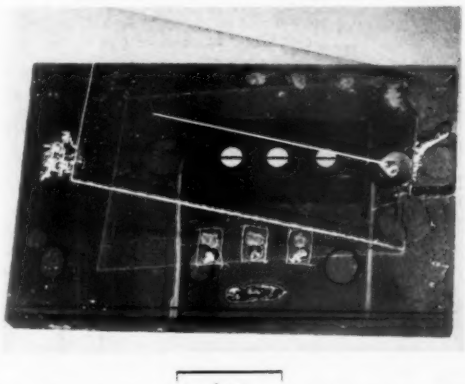

Figure 7. Set of three tin Crowe cells with drive wire tilted up to show structure. Crossbar width 0·02 cm

the critical current of the crossbar consequently falls abruptly (this is not shown in *Figure 8* for the sake of simplicity). Before it will return to the superconducting state time must be allowed for the removal of this heat to the mica substrate, and the trailing edge of the drive pulse must be delayed until this thermal recovery time has elapsed.

We can write approximately, $\tau_{\text{thermal}} \simeq C/K$, where C is the thermal capacity of the superconducting crossbar, and K is the thermal conductance of heat between it and the substrate. Tin elements have been shown to be capable of much more rapid switching than lead, and one reason for this is undoubtedly the considerably lower specific heat of tin at these temperatures.

The actual response of the tin elements used at the Royal Radar Establishment is shown by the oscilloscope traces in *Figure 9*, where drive current pulses of rather triangular shape, about 50 mμsec in width across the base, have been used. The disappearance of the pick-up signal in the absence of a full-level write pulse preceding the read pulse is clearly shown. This behaviour will be clearly understood by comparison with *Figure 8*. By gradually reducing the length of the drive pulses the minimum time required for switching different tin elements has been investigated, and an average value of about 10 mμsec has been observed. It is probable that both the L/R constant and the thermal recovery time for these tin elements are of this order of magnitude. Thus, without any particular difficulty, the Crowe element can be made to operate about 100 times as fast as the best ferrite cores. Since the speed of existing computers is limited mainly by the access time to the store, we have here the possibility of achieving a very substantial improvement, provided that the problems associated with the use of a superconducting store can be solved.

Problems of a Low Temperature Computer

Because it has current gain, the cryotron is in principle capable of fulfilling the requirements of all the logical elements in a computer as well as those of the store, so that the whole computer, apart from its input and output, could work under liquid helium. However, this is not true of the Crowe cell working alone. It is a memory device only, and must work in conjunction with other active elements, and in particular a large store consisting of Crowe cells will require a large number of

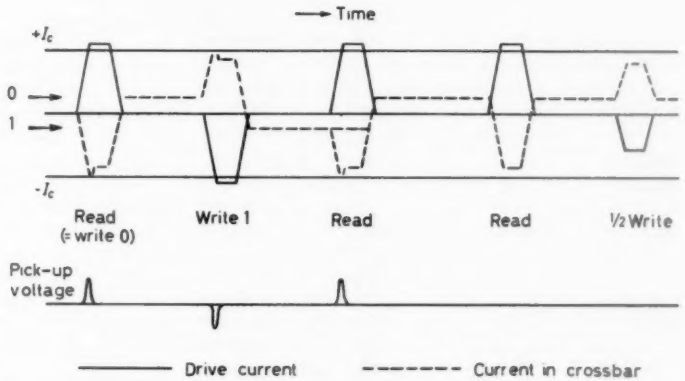

Figure 8. Mode of operation of Crowe element (after Lock, Engineering (1959) 187, 550)

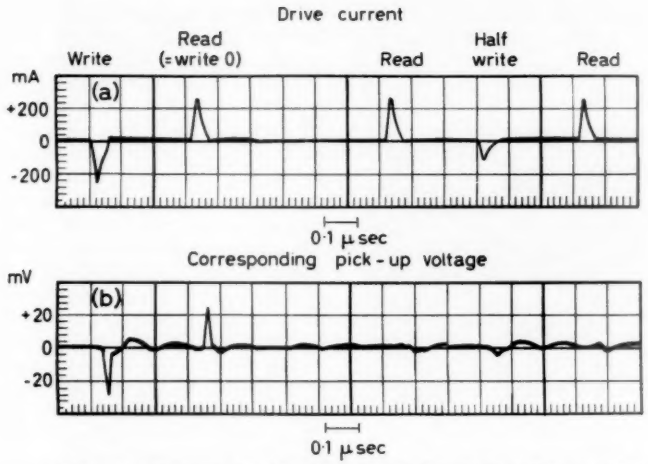

Figure 9. Response of 2 mm diameter tin element at 3·2°K; (a) drive current, (b) corresponding pick-up voltage. No pick-up signal is obtained unless the element changes from one state to the other. To interrogate a 'write 0' ('read') pulse is applied. If a '1' is stored a voltage pulse appears on the pick-up wire, but if a '0' no pick-up signal is obtained. A half level write pulse is insufficient to switch the element and therefore coincident current selection, using two drive wires, is possible

selection circuits to provide random access to it, even when use is made of coincident current drive. In order to avoid too great a conduction of heat to the liquid helium bath down electrical leads, these selection circuits must themselves be capable of operation at a low temperature. Semiconducting devices can probably be used for this purpose, and experiments to test their behaviour in liquid helium are now in progress and are already yielding promising results. It is quite likely that such devices will enable not only the necessary selection and gating to be carried out, but the arithmetical and logical functions of the computer too, so that just as with the cryotron the entire high-speed circuitry may operate in liquid helium.

The problem of refrigerating a high-speed store to the necessary low temperature, with or without the rest of the logical circuitry, is not as severe as might appear at first sight. The actual power dissipation involved in switching a Crowe element is quite remarkably small, usually about 10^{-10} J, so that, even assuming an average of fifty elements switched at once at a rate of 50 Mc/s, the total power would be only 0·25 W. Actually the heat conduction down the leads from the 'outside world' would inevitably be considerably greater than this, but it can be calculated very roughly that it could be kept down to a value of about 1 W. A liquefaction rate of about 2 l. of liquid helium per hour would be sufficient to make good the evaporation losses due to this rate of heating, and for this purpose a comparatively small and cheap helium liquefier would be adequate.

In conclusion, it seems that the new superconducting devices described in this article really do open up a new range of possibilities in the field of high-speed computing. It is true that much work needs to be done to achieve adequate reproducibility of the individual elements, and this needs careful control of the evaporation process. There can be little doubt, however, that problems of this nature will be overcome, and the methods used should be capable of adaptation to the production of large arrays of elements both quickly and cheaply. These are, of course, important factors in considering the financial implications of any new device. The great increase in speed obtainable with these superconducting elements should provide the necessary incentive for solving the further problems associated with their development for large and fast computers.

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VIRUS RESEARCH

With Special Reference to Chemotherapy

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Recent work on the structure and growth of bacterial and animal viruses is described. More is known about virulent viruses but those which do not cause obvious damage to the host can now be studied in tissue culture. Chemotherapy is still largely empirical because knowledge of protein and nucleic acid metabolism is limited but experimental approaches to chemotherapy are discussed.

Most branches of Virology have shown considerable advances in recent years[1]* and knowledge of virus structure and growth is now being applied to the search for anti-viral drugs. There are at present no chemotherapeutic drugs for the treatment of clinical infections caused by the smaller viruses but reviews on experimental chemotherapy have appeared[2,3]. These viruses can thus be easily and accurately parasites. The estimate of their size varies slightly with the method used (filtration, centrifugation, and electron-microscopy) but the viruses include agents ranging from about 15 mμ, *e.g.* poliomyelitis virus, to about 200 mμ, *e.g.* smallpox virus. In addition, there are the *large viruses* which are about 200–300 mμ, *e.g.* trachoma and psittacosis viruses, and the arthropod-borne *rickettsiae* which are somewhat larger, *e.g.* typhus fever. The large viruses are susceptible to chemotherapy clinically and experimentally and some people would exclude them from the *true viruses*, although they fit the usual definition of virus.

Virus Growth

The structural development of virus particles in the cell has been followed by the use of the electron-microscope. This is particularly valuable when changes are correlated with biochemical and serological changes. Very thin sections embedded in plastic can be examined (*Figure 1*) but several hundred sections are needed to examine a cell completely. Hence interpretation is sometimes difficult, particularly when the smallest viruses are being studied. By concentrating virus suspensions from infected tissue and using a negative staining technique, in which specimens are treated with phosphotungstic acid and sprayed onto the electron-microscope grid, virus particles can be examined in finer detail (× 500,000 or more). By this technique poliomyelitis virus has been shown to be an icosohedron with 60 sub-units, each of 60Å diameter, thus confirming x-ray diffraction studies[4].

The fluorescent antibody technique[5] can also be used to follow virus multiplication within a cell. By this method viral antigens in the cell are picked out by the ordinary light microscope using specific antibody coupled to a fluorescent dye.

Although cells have been grown in tissue culture since the end of the last century, the early technique was tedious and not suitable for viruses which were at that time grown in susceptible laboratory animals and, later, in fertile eggs. The egg technique has been very useful for virus study, particularly for influenza virus, but some viruses will not grow in eggs. Furthermore, it is a complicated system and not suitable for quantitative biochemical work.

In 1949 poliomyelitis virus was grown in cells of non-nervous origin in tissue culture, producing cytopathic changes[6]. Antibiotics to suppress bacterial contamination became available at about that time so there was a great impetus to the study of many viruses in tissue culture. Since then several ' pure ' cell lines have been established and these can be grown directly on glass as monolayer cultures. Certain viruses grow on these monolayer cultures, producing areas of dead cells which can be seen as ' plaques ' against a stained background of live cells. These viruses can thus be easily and accurately assayed; the technique corresponds to the plaque technique for bacterial viruses (*Figure 2*) or the poxes produced on egg chorio-allantoic membrane (*Figure 3*). Some cell lines can be grown in suspension and such cells are more uniform and, therefore, more suitable for quantitative biochemical

* Where possible review articles have been cited as there are too many references to quote in full.

work. Paper chromatography and isotope techniques can be used to follow biochemical changes and studies with the animal viruses are now following up the pioneer work of DELBRUCK, COHEN and others on the bacterial viruses (bacteriophages or phages—*Figure 4*) between 1940 and the present date[7].

Summarizing this fascinating field, from data obtained chiefly from the T-even phages of *E. coli*, a phage has a hexagonal head and a narrow cylindrical tail with four or five fibres at the end. It consists of about 40 per cent desoxyribose nucleic acid (DNA), which is in the head and the rest is mainly protein; there are several proteins in the tail. The phage is adsorbed to a sensitive bacterium by its tail; the subject of adsorption is complex and a recent review covers many references[8]. There is strong evidence that a zinc–protein complex in the cell wall is involved in the unwinding of the phage tail fibres, which are attached to each other by thiol–ester bonds. An enzyme in the tail hydrolyses part of the cell wall and the DNA from the head enters the bacterium, leaving the protein overcoat outside.

HERSHEY and CHASE[9] infected cells with phage labelled by isotopic S or P, agitated the suspension and found that the S labelled protein was sheared off, while the DNA (P label) entered the cell. The DNA appears in phage progeny but not more than 3 per cent of the phage protein enters the cell and neither this nor the acid soluble peptide is transferred to the progeny. After adsorption the infectious phage disappears and there is a definite time interval (as low as ten minutes in some cases) called the latent period, after which the cell bursts and several hundred phage particles come out. New virus can be detected by breaking open the cell half way through the latent period.

The cell metabolism changes after infection; the production of host DNA stops and phage DNA appears after a time interval. One phage contains a unique purine, 5-hydroxy-methyl-cytosine, and this can be used as a virus label; the enzyme responsible is an example of a virus induced acquisition of a metabolic function[10]. Protein synthesis continues throughout; a vital non-specific protein is synthesized before any DNA can be synthesized and phage specific protein appears before any complete phage particles are made. The phage protein is synthesized from free amino acids but the DNA comes both from host cell nucleic acid and the medium and no larger units than nucleosides or nucleotides are involved. The final stages may involve condensation of DNA which has to fit inside the head, the surrounding of this by protein and the formation and attachment of the tail, to give mature phage (*Figure 4*). Thus the protein acts as a carrier for the DNA which cannot infect a bacterium itself. The protein is also responsible for the serological specificity of the virus and phage protein without the DNA can kill a bacterial cell, even though this does not lead to any progeny.

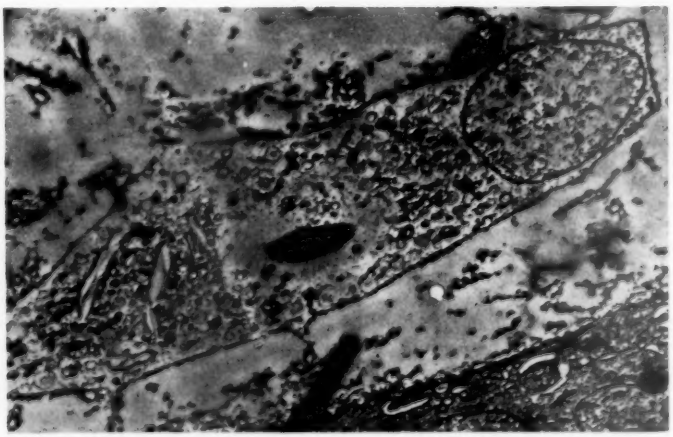

Figure 1. Electron-micrograph of a section of a cell of egg chorio-allantoic membrane infected with ectromelia *virus (× 10,000 reduced by ½). The nucleus is at the top right, the virus particles are the small dark bodies and the large dark central body is part of the virus inclusion body*

These studies on phages have greatly influenced work on animal viruses in tissue culture. The general sequence of events is similar but far less detail is known. After adsorption there is an eclipse period. There is a latent period followed by a release of virus although this may be over a period of hours. Unlike phages, animal viruses do not have tails and do not contain large amounts of nucleic acid. Host cell material is often closely associated with the virus and may be an integral part of some viruses, *e.g.* influenza.

Although the larger animal viruses contain some DNA others contain only ribosenucleic acid (RNA). Recent values for influenza virus[11] are RNA 0·8 per cent, lipid 18 per cent, polysaccharide 5–7 per cent, the rest being protein. If the lipid is removed by ether, two non-infectious sub-units are obtained, one containing the RNA.

It is not possible to follow the production of animal viruses in a cell by labelling the nucleic acid or protein since only about 1 per cent of either in the cell consists of virus material. Nor has any unique constituent, corresponding to 5-hydroxymethyl-cytosine, been identified.

The importance of nucleic acid has been re-emphasized by experiments on the infectivity of RNA from virus-infected cells[12]. DNA was known to carry the hereditary principle of phages and in 1956 DNA from tobacco mosaic virus was found to be infective; it could be combined with viral protein to form virus. Similarly, infectious RNA has been extracted from tissues infected with the smallest animal viruses but not from tissues infected with the medium-sized or largest viruses. The infectivity is always much lower (about 0·1 per cent) than that of intact virus.

Animal viruses can be obtained in good yields from tissue culture cells maintained in simple buffered salt solutions plus an energy source such as glucose. Even if the amino acid pools are depleted by starvation by 90 per cent there is enough reserve material to produce poliomyelitis virus[13] and we have found similar results for influenza virus. However it is possible to stop virus production in tissue culture by certain amino acid antagonists which are selectively more harmful to virus synthesis than to the host cell. These can be highly specific, *e.g.* L-*threo*-β-phenylserine is active but not the D isomer or either of the *erythro* forms[14]; this substance is competitively antagonized by L-phenylalanine.

Multiplication of virus in the host animal is controlled by many factors, apart from those which can be studied in tissue culture. The presence of specific antibody is obviously important in arresting the development of an infection. Non-specific factors may play an important role but their significance is not clear. Age of host, nutritional factors, hormones and temperature have all been implicated in some cases[15].

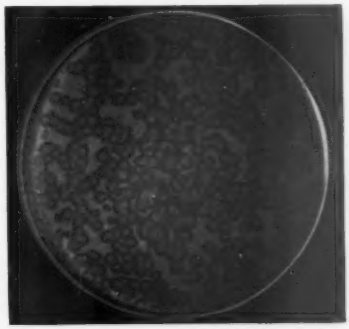

Figure 2. Plaques produced by a temperate bacteriophage of Pseudomonas pyocyanea *on a plate seeded with its host. (Reduced by ½). Each plaque (in this case a central zone of lysogenic bacteria surrounded by a lytic zone) arises from one infectious unit. This is a convenient and accurate means of titrating bacteriophages*

Virulence and Latency

Viruses differ greatly in their virulence and it is not known what makes a strain 'a killer'. Growth rates and resistance to environmental factors have been studied but are certainly not the determining factors in many cases. A sudden epidemic is usually evidence of a 'new' virus at large in a population, but eventually some sort of balance is achieved. Myxomatosis killed 99·8 per cent of the rabbits in Australia when first introduced but within two years the figure was about 90 per cent. Some new viruses are relatively harmless; infection caused by the Asian strain of influenza virus did not have the high mortality rate of the 1918 pandemic.

Virulent bacteriophages which have been described above can arise as mutants of 'temperate' phages which do not normally lyse their host. Temperate phages are adsorbed and penetrate into the bacterium but the host is not lysed and the cell's progeny all carry the *potentiality* to produce phage, *i.e.* they can be induced by suitable means, *e.g.* u.v. light, to produce temperate phage. A small proportion of the cells do lyse spontaneously, thus providing some free phage in these 'lysogenic' cultures which are immune to their own virus. The protein coats of temperate phages, unlike those of virulent phages, do not kill the bacterial hosts. The

subject of lysogeny has been reviewed recently[16]. If is of particular interest since more and more animal viruses are being discovered which are latent in the host but cause no obvious symptoms.

Animal cells can carry viruses, often indefinitely, but the mechanism is not always clear. Some animal viruses can be perpetuated in tissue cultures of mixed sensitive and resistant cells. Virus in some animals only appears to be non-infectious because it is masked by the presence of antibody and can be demonstrated by special means. Many 'new' viruses have been discovered in animal hosts (in which they often cause no apparent damage) by the changes produced in tissue culture cells. It is thought that perhaps some tumours caused by viruses may be analogous to lysogenic cultures, since the tumour cells are not destroyed but multiply and liberate virus at a very slow rate, about one infectious unit per cell every few hours[17].

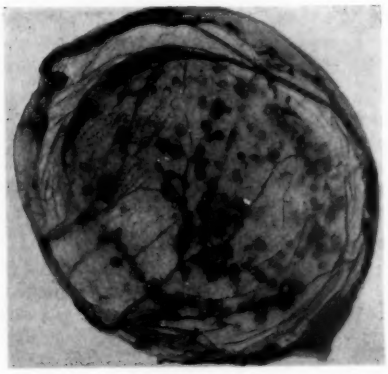

Figure 3. Lesion produced by vaccinia *virus on egg chorio-allantoic membrane (approx. natural size). Each lesion arises from an infectious unit and consists of proliferating cells which become necrotic*

Theoretical Approaches to Chemotherapy

From present knowledge, virus diseases can be attacked, at least in theory, in various ways.

(*1*) *Inactivation of free virus*—This has limitations since viruses are mostly intra-cellular. Even specific antiserum has limited effect when given after infection, although specific immune serum or α-globulin is sometimes given to cases of recent exposure where a special risk is involved. Another approach, that of aerosols to inactivate virus-infected droplets in the air, has been unsuccessful to date.

(*2*) *Prevention of adsorption and penetration*—As far as animal viruses are concerned, there is not enough knowledge to try to attack these stages.

(*3*) *Prevention of multiplication of virus in the cell*—This approach is attractive but difficult because one must interfere selectively with either protein or nucleic acid metabolism, about which little is known. It is not known whether proteins are formed directly from amino acids *via* a template mechanism or whether small peptides are involved as intermediates. HOAGLAND[18] has studied amino-acyl-adenosine monophosphate compounds which are thought to be involved in the activation of amino acids before incorporation into proteins. More work on protein and nucleic acid synthesis is needed before rational anti-viral chemotherapy can be instituted. However, empirical methods may suggest metabolic pathways.

(*4*) *Prevention of release of virus from the cell*—Although periodically put forward, this seems impracticable.

(*5*) *Prevention of damage caused by the virus*—If virus multiplication is prevented, then damage is prevented also, but it may be possible to prevent the damage by other means, *e.g.* by stimulating the host defences. The production of immunity is outside the scope of this article but much research is directed at obtaining more potent vaccines.

(*6*) *Interference*[19]—One virus may infect a cell and prevent the growth of a second virus in the same cell under certain conditions. This was first studied with bacteriophages but it also applies to some combinations of animal viruses. The first (interfering) virus may be modified by heat or u.v. in some cases. Inactivated influenza virus can protect cells in tissue culture and this protection is mediated by a protein, interferon. There appears to be some tissue specificity which may limit the usefulness of this approach.

Various drugs have been shown to interfere with one or other of the various stages of infection in tissue culture or chick embryo but there have been no useful effects in animals. It has, in fact, been suggested that no anti-viral drug can ever be successful clinically since the damage is done before symptoms appear. However, all cells are not affected at once, and in many diseases there is certainly as much time as is available for successful anti-bacterial therapy. This pessimistic view can easily be refuted experimentally in the case of a large virus. Sufficient mouse pneumonitis virus is given to cause lung lesions in all mice and to kill half of them between eight and fourteen days after infection. Treatment can be commenced six days after infection, when the mice are very ill, and all will survive; in fact, they resist a challenge dose of virus, given a few weeks later, better than mice

treated from the start of infection, since they have produced more antibody.

Obviously, the testing of drugs for anti-viral activity is more difficult and much more expensive

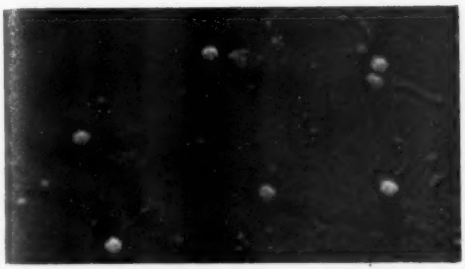

Figure 4. Electron-micrographs of a bacteriophage of Pseudomonas pyocyanea *(×111,000 reduced by ½)*

than testing them for anti-bacterial activity. Since living cells have to be used the system is complicated and all drugs toxic to the host are ' inactive ', even though they may possess intrinsic anti-viral activity. Some workers test primarily in mice but this weighs the scales heavily against a drug. In the search for drugs acting on the multiplication of viruses, it seems logical to test first in the simplest systems (fertile eggs or tissue culture, but the latter is more laborious) and to cover a range of viruses. Our own scheme[20] includes influenza and representatives of the main virus groups as well as bacterial viruses for certain purposes, *e.g.* work on mode of action and drug assays. Preferably the test virus should be of clinical interest, but primarily it should be easy to handle experimentally, *i.e.* it should grow in tissue culture, eggs or mice. It should be fairly stable and preferably a simple assay, *e.g.* haemaglutination should be available. Stocks of known titre can be kept either at −70°C or freeze-dried.

If a drug is active in the simple primary test, the mode of action can be found and the further tests done in animals. Apart from inactivation, and excretion factors, it may be impossible to get the required drug concentrations in the tissues before the toxic level is reached.

Since laboratory tests in eggs and mice will pick out drugs, such as the tetracyclines which are active against the larger viruses clinically, there is no obvious reason why useful drugs against small viruses should be missed. However, no scheme can cover everything; one directed primarily at virus multiplication may miss a drug acting on host responses if the effect is species specific. The specialized location of some viruses makes experimental approach difficult, *e.g.* the eye withstands large amounts of some drugs which would be toxic to the usual laboratory hosts. Therefore, drugs active against trachoma virus (which causes blindness) may be missed if the tests are carried out in eggs in which this virus has recently been isolated. Drugs to be tested against the common cold must be tested in human volunteers since this virus cannot yet be grown in the laboratory.

Experience with the experimental and clinical treatment of infections caused by the larger viruses plus knowledge of latency, sometimes life-long of many viruses, suggests that latent infections will be a problem after treatment. Unless therapy is prolonged, much beyond that needed to produce an immediate clinical improvement, animals remain carriers of the larger viruses apparently indefinitely and, as in man, relapses occur. However, this problem can be left for the future, when it does not seem impossible that drugs active against the small viruses will be available.

I wish to thank Dr Craik of Messrs Boots Plant Laboratory for the electron-micrographs.

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ROCKET PROPELLENTS

Part II. Solid Propellents

W. G. PARKER

In the introduction to a previous article the two principal types of rocket motor were illustrated. One of these which uses liquid propellents was discussed and the other which has the propellent in solid form, ready filled in the combustion chamber, is considered here. The familiar firework rocket is a crude form of solid propellent motor and up to the Second World War the rockets which were employed for military purposes or in the more humane rocket equipment for life-saving (introduced at the beginning of the nineteenth century) used pressed powders rather like those contained in fireworks. In the last twenty years, however, much better performance has been achieved with the introduction of double-base and composite propellents, and solid rockets now have many uses.

As WITH liquid propellent rockets* the last war also marks the beginning of modern technology for the solid motor with the introduction of the cordite rocket and an ever increasing research and development effort on new and improved compositions.

In a sense a solid propellent is a mono-propellent with the oxidizer and fuel components intimately mixed. Combustion takes place close to the surface and the combustible gases are continuously evolved from the surface which recedes uniformly as the propellent is consumed. To be satisfactory the propellent must possess a number of special properties as follows:

(*1*) On ignition the ingredients must vaporize and be capable of undergoing a strongly exothermic reaction to produce gases at high temperature. The basic relationship between performance and the properties of these gases holds as for the liquid motor and again the specific impulse is proportional to $\sqrt{(Tc/\bar{M})}$ where T_c is the combustion temperature and $\bar{M}$ the mean molecular weight of the product gases.

(*2*) Combustion must take place in an orderly fashion and the rate of burning must not be unduly influenced by the combustion pressure or the temperature of the solid.

(*3*) The solid should have suitable viscoelastic properties over a wide temperature range (*e.g.* $-40°C$ to $+50°C$) and must not crack or flow. It should preferably be capable of bonding directly to the motor casing.

(*4*) The propellent must have good stability and storage properties over a long interval of time (*e.g.* two years) and must not be sensitive to heat or shock.

Other properties such as a high density are desirable also but the combination of so many properties is difficult to achieve and the potentially wide range of chemical systems has narrowed down to two main classes which are known as double-base (or colloidal) and composite propellents.

* See Rocket Propellents Part I, *Research* (1960) XIII, 26

Double-base Propellents

These are all modifications of nitrocellulose plasticized with a nitric ester (usually nitroglycerine) and a stabilizer. The British cordites belong to this class of colloidal propellent and a typical composition is

Nitroglycerine	41 per cent by weight
Nitrocellulose	50 per cent by weight
Carbamite	9 per cent by weight.

Carbamite (diethyl diphenyl urea) is added to bring about gelatinization of the nitrocellulose by the nitroglycerine and to act as a stabilizer by neutralizing decomposition products of the nitric esters. Other substances are added to produce desirable ballistic characteristics (carbon black, inorganic salts *etc.*) and to modify the energy available (triacetin and various phthalate esters).

The manufacture of this kind of propellent involves not chemical reactions but the penetration of nitrocellulose fibres by nitroglycerine which is a physical process and can be brought about in several ways. At first it was done with the aid of a volatile solvent which was evaporated from the product afterwards. Unfortunately the diffusion processes on which this depends are slow and only very small solid charges or 'grains' can be produced in this way. Next a solventless process was evolved in which the ingredients are first blended to obtain a certain amount of swelling and then intimately mixed at high pressure between heated rollers. Temperatures of between 70° and 90°C are employed and on account of the high fire risk involved, the process is isolated and conducted by remote control. The final grain is formed by extruding the propellent through a heated die and then annealed to relieve residual stresses before an inhibitor

coating is placed on the outside. This inhibitor is necessary because double-base propellents do not have good viscoelastic properties and cannot be bonded directly to the steel case of the motor. Ethyl cellulose and cellulose acetate are most widely used as the inhibitor and are applied either by winding on as a tape or as a tube which is shrunk on to a cylindrical grain.

Generally speaking the solventless extrusion process has proved very successful for the production of grains of moderate size but it is not suitable for very large grains which have a diameter of more than about twenty inches. Some extension of size and varieties of shape have been achieved through the development of a casting process. In this a granular casting powder in the form of tiny rods is first prepared by a solvent extrusion process. This powder contains the nitrocellulose and other solid ingredients with some nitroglycerine. It is placed in a mould of the required shape and evacuated to remove volatile solvent and air. A mixture of nitroglycerine and other plasticizers is introduced and fills the interstices between the granules of powder. The temperature is raised to about 60°C and the charge allowed to cure for several hours. During this time the nitroglycerine diffuses into and swells the granules which coalesce into a uniform mass. Finally the charge is allowed to cool and the mould taken apart leaving the grain ready for installation in the motor casing.

Current research is attempting to simplify and cheapen the casting process by using slurry methods which do not require the preparation of a special granular casting powder.

Propellent specific impulses of up to 240 seconds may be obtained with double-base compositions. The principal disabilities of this class are chemical instability at temperatures of 50°C or more and the poor viscoelastic properties already mentioned. It has been found that these properties are related to the nitrocellulose content and for a given temperature the tensile strength and elastic modulus increase with increasing amounts of nitrocellulose but the elongation decreases. For most practical compositions brittleness sets in at about −20°C. Changing the plasticizer from nitroglycerine to diethylene glycol dinitrate (D.G.D.N.) produces rather better physical properties but the propellent is not as satisfactory in other ways[1].

Composite Propellents

These are essentially mixtures of an inorganic oxidizer and a fuel. Black powder, originally used in early forms of rockets, belongs to this class but its performance ($SI \sim 70$ sec.) and mechanical properties are relatively poor and much better compositions have now been evolved. Of the oxidizers available the nitrates and perchlorates are the most promising and have a high oxygen content as shown in the following *Table 1*.

Figure 1. Launching of a Skylark rocket at Woomera[6]. (Courtesy Royal Aircraft Establishment. Crown copyright reserved)

In general the perchlorates contain more oxygen but have the disadvantage of producing acid fumes (HCl). Moreover the lithium, sodium and potassium salts give rise to solid products in the exhaust. For these and other reasons such as deliquescence in the case of lithium the oxidizers most widely used now are ammonium perchlorate and ammonium nitrate.

Table 1

Oxidizer	*Oxygen content per cent by weight*	*General properties*
Lithium nitrate	58	Crystalline. Deliquescent in moist air
Sodium nitrate	47	Crystalline. Stable in moist air
Potassium nitrate	39·5	Crystalline. Stable in moist air
Ammonium nitrate	20	Crystalline with phase transition (rhombic→ monoclinic) at 32·1°C
Lithium perchlorate	60	Crystalline. Deliquescent in moist air
Sodium perchlorate	52	Crystalline. Deliquescent in moist air
Potassium perchlorate	46	Crystalline. Stable in moist air
Ammonium perchlorate	25·2	Crystalline. Stable in moist air

The fuel, which acts also as a binder, may be chosen from a wide variety of substances and YOUNG[2] has subdivided composite propellents into rigid, elastomeric and thermoplastic according to the nature of the binder.

Rigid Composites

Like the earlier black powder propellents these composites are produced by compacting mixtures of oxidizer and fuel at high pressure. They do not now play a large part in rocket propulsion but compositions based on ammonium nitrate are used for gas generators, power cartridges *etc.* The virtues of ammonium nitrate are its cheapness and the low toxicity of the gases produced. Moreover the temperature of these gases can be varied over a wide range by a suitable choice of fuel and combustion will occur at any pressure if a suitable catalyst is added. One of the disadvantages in the use of this oxidizer, apart from its hygroscopic nature, is the crystal phase change which occurs at 32°C and causes a volume change which leads to cracks in the charge. Recent work claims to have overcome this volume change by using mixed crystals of ammonium and potassium nitrates.

Elastomeric Composites

Rubbery propellents based on ammonium perchlorate and on ammonium nitrate in conjunction with rubber polysulphides (*Thiokol*), polyvinyl chloride, polystyrene or synthetic rubber have been developed particularly in the U.S.A. The latest and most promising ones use polyurethane as binder and are said to have a high performance, good physical properties and good heat stability. ZACHRINGER[3] reports that this type of composite is used by the Aerojet General Corporation in large rocket sustainer motors. All elastomeric composites are or should be capable of bonding directly to the rocket motor casing. Most of them have poor stability at high temperatures and undergo a slow change in mechanical and ballistic properties during storage.

Thermoplastic Composites

An early development of this type which showed thermoplastic properties at elevated temperatures consisted of ammonium nitrate or potassium perchlorate bound with asphalt. These compositions were discontinued because of the limited temperature range over which they could be used, and the marked effect of pressure on burning rate. A more recent development which has been successful in the United Kingdom is a composition based on ammonium perchlorate and poly*iso*butene. The burning rate is fairly high but can be reduced by suitable additives, and a series of compositions known simply as 'plastic' propellent contains ammonium picrate as a major ingredient which acts as a coolant and combustion stabilizer. The merits of plastic propellents are its unequalled chemical stability and good storage properties; its limitations are a tendency to cold flow and to embrittlement at low temperature. Propellents of this type are used in the Raven motor of the British Skylark sounding rocket shown in *Figure 1*.

As a class, composite propellents are fairly simple to manufacture. The particle size of the oxidizer is often important and affects the burning rate of the propellent. Also it is usual to incorporate additives which do this and modify the ballistic and mechanical properties of the final product. Some risk is involved during mixing of the oxidizer and the fuel, particularly at the beginning when the mixing is not uniform and the local concentration of oxidizer may be high. Also mixing is often carried out at elevated temperature. The mixing time is usually fairly critical and the product is then pressed into a mould or directly into the motor casing and cured at a suitable temperature. A variety of changes such as polymerization take place during the curing period.

The advantages of composite over double-base propellents are lower cost, easier manufacture and suitability for case bonding which avoids the dead

weight of an inhibiter. The performance of the composites at present is equal to that of double-base.

Burning Rate and Performance

Solid propellents burn by a process of deflagration in which the principal exothermic flame reaction occurs in the gas phase close to the solid surface. Heat is conducted to the surface and is responsible for the continuous evaporation of the solid with or without liquid phase reaction at the surface. The rates of burning are of the order of inches per second and deflagration is quite a different process from detonative burning which takes place in high explosives and for which the velocities are 10^5 greater. The transition from deflagration to detonation can occur under certain conditions however and the sensitiveness of a propellent to the change must be determined during the development stage. In general the more energetic a propellent the greater its sensitivity, and this is one of the difficulties accompanying the development of high energy solid propellents.

It has been known for some time that at gun pressures the rate of burning of cordite depends on the calorific value but at rocket motor pressures (1000–2000 lb/in.^{2}) this is not always the case. The rate of burning R_B depends on the nature of the propellent and is affected by the combustion pressure

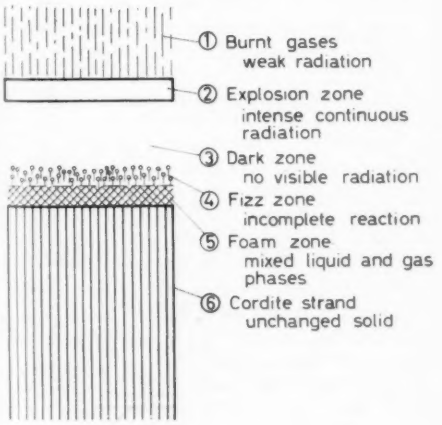


Figure 2. Structure of a cordite flame

P_c, the temperature of the solid, and the flow of gas over the surface. An empirical relationship of the type

$$R_B = a\,P_c^n$$

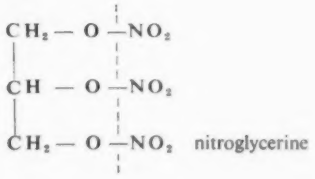
is found to hold over certain ranges of pressure; a is a constant and n is also a constant known as the rate of burning index. YOUNG[2] has given some typical ranges of values for R_B and n for the different classes of solid propellents described above. Young's values are reproduced in *Table 2.*

Table 2. Rates of burning (R_B, in./sec.) and pressure exponents (n) for different types of propellent

	Type of propellent		
	Double-base	*Ammonium nitrate*	*Ammonium perchlorate*
R_B	0·3 –0·8	0·05–0·45	0·1–0·8
n	0·40–0·85	0·35–0·65	0·3–0·7

The value of n is one of the determining factors in selecting a propellent. It must be less than unity for stable combustion and a low value is desirable, while a burning rate which is independent of pressure would be ideal. This ideal has been achieved over limited pressure ranges with some compositions. The value of n is not always constant over all ranges of pressure however and a change is frequently observed with ammonium perchlorate propellents in the region of 1000 lb/in.^{2}

There is a wealth of empirical information and 'know-how' about the influence of different factors on burning rates. With ammonium nitrate compositions variation is brought about by changes in the amount of catalyst or fuel and the particle size of the oxidizer has little effect while with ammonium perchlorate the mean particle size has a marked effect on burning rate in addition to changes brought about by variation of the fuel/oxidizer ratio. Detailed knowledge of the mechanism of combustion is still lacking however. A number of excellent studies have been conducted some with the aid of window bombs in which spectroscopic and other measurements were made. These have helped to elucidate the structure of the flame which in the case of double-base propellents possesses a number of zones as shown in *Figure 2.* It is generally accepted that the combustion of cordite like that of the simple nitric esters begins with the breaking of the weakest bonds which link the nitrate groups to the nitrocellulose and the nitroglycerine molecule, *e.g.*



This step is endothermic but is followed by an exothermic reaction in the dark zone between the resulting NO_2 and organic fragments (especially the CHO group) of the original molecule producing NO, CO and hydrogen, which finally react together, and with the remaining organic material in the explosion zone. HEATH[4] found that the radiation from the explosion zone is substantially black body radiation and he attributes this to carbon particles present in the flame. It is possible that the reaction between nitric oxide and carbon triggers off the flame reaction in the explosion zone.

With composite propellents and particularly those incorporating ammonium perchlorate the luminous reaction zone occurs very close to the solid surface and detailed study is even more difficult than with cordite. Some interesting fundamental work has been done on the thermal decomposition of ammonium perchlorate which seems to indicate that the rate determining step at temperatures above about 350°C is a proton transfer on the surface of the solid which produces ammonia and perchloric acid[5]. The latter is unstable and in the absence of an added fuel oxidizes the ammonia so that the decomposition can be represented by the overall reaction

$$2\ NH_4ClO_4 \longrightarrow 4H_2O + 2NO + O_2 + Cl_2$$

Motor Design

From *Table 2* it will be observed that the range of burning rates for solid propellents is fairly restricted. In practice it amounts to approx. 0·05–1·4 in./sec at combustion pressures of around 1000 lb/in.^{2} and this restricted range is due to the limited number of suitable oxidizers. This fact has to be accepted at present in the design of solid motors. The overall requirement for a motor is usually a given thrust for a given time and to meet this the designer must choose his propellent and work out the grain geometry which will give him the required thrust at a suitable combustion pressure. To maintain constant thrust the surface area must remain constant as combustion proceeds and with cylindrical grains this may be done in two ways, either by having end burning (like a cigar) or by burning in a longitudinal conduit which is shaped like a star or similar pattern in cross-section. Two common shapes are shown in *Figure 3*. End-burning has several limitations: the thrust is usually small unless the burning rate is high; the case is exposed to the high temperature gases as the propellent recedes; and lastly the centre of gravity of the motor is continually shifting. Longitudinal conduits with burning progressing towards the side of the case is therefore the more usual and has the advantage that the case is protected from the hot gases up to the time that the propellent is exhausted. Burning is usually quite uniform, and it is inevitable that the initial pattern of the conduit will remain at the end in the form of longitudinal slivers as shown in *Figure 3b*. This represents a weight loss and attempts have been made to replace these slivers with less dense material. Constant thrust is not always required and the design may be varied to give changes of thrust according to a predetermined plan. The thrust/time curve of the Raven motor used in the Skylark rocket (*Figure 1*) is reproduced in *Figure 4* and shows a high initial thrust which the designer wanted to accelerate the rocket in initial stages of flight[6].

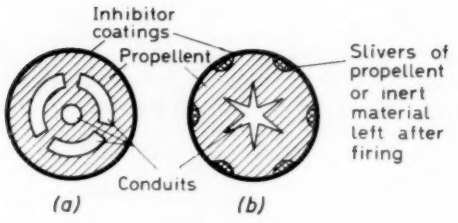


Figure 3. Cross sections of two typical grains designed to give constant area of burning surface

Solid versus Liquid Motors

In the last war solid rockets were used mainly for small offensive and defensive weapons and for the assisted take off units for heavily laden aircraft. Since that time higher specific impulses have been achieved with solids and much larger grains have been made with the result that solid motors have invaded the field previously held by liquid propellents. Preference for solid motors us understandable. A liquid propellent rocket is rather complicated and requires much precision engineering while solid motors using composite charges are less expensive to make and relatively simple to handle.

Published information on rocket-propelled weapons in use or under development in the U.K., U.S.A. and France shows that all air to air weapons have solid motors and so have nearly all surface to air weapons. Air to surface weapons use various forms of propulsion including solid and liquid rockets and turbo-jets. All anti-tank weapons use solid propellents and solid motors are invading the ballistic missile field. The American Sergeant missile for example which is in service and has a range of over two hundred miles has a solid motor (Thiokol) while their two stage Polaris missile which is under development and will have a range of over

1500 miles uses solid motors for both stages. Solid motors are also coming into use in the final stages of vehicles for launching satellites and space probes and the third stage of the Russian Lunik vehicle is reported to be a solid motor.

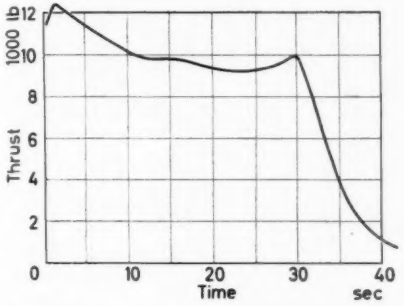


Figure 4. Thrust–time curve of a Raven motor used in the Skylark rocket[6]. *(Courtesy Royal Aircraft Establishment. Crown copyright reserved)*

In spite of this impressive progress, solid motors have certain disadvantages compared with their liquid counterparts. The thrust can only be varied by a predetermined plan and cannot be altered on command during flight. Total thrust is limited by grain size and the production of very large grains free from imperfections is a continuing development problem. The safety of handling very large grains may be questioned and their transport may prove a limiting factor. For this reason suggestions have been made that the propellent should be made at the launching pad and filled into the motor casings *in situ* rather like the mixing of concrete to fill a large caisson. That day is some way off, however. Lastly, it seems unlikely that solid compositions will ever equal liquid propellents in performance. The present limit of about 240 sec for solids is determined by the chemical equilibrium at high temperature of gases involving the elements hydrogen, carbon, nitrogen and oxygen. The temperature of combustion can be raised by the introduction of some of the lighter elements or their hydrides but the benefit is probably not great and is soon offset by the rise in molecular weight of the products. Also the chemical stability of mixtures containing these elements may be poor and their sensitivity to detonation may be high.

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1960 ESSAY COMPETITION FOR SCHOOLS

THE *Research* Essay Competition for Schools was instituted in 1957 with the purpose of encouraging scientifically-minded school pupils to write clearly and comprehensibly about their work; thus it was hoped to assist in raising the standard of the writing of scientific reports in the future.

The 1960 competition has reverted to its original form. Schoolboys and schoolgirls are asked to write a report of 1000 to 1500 words on any recent piece of practical work or special project they have carried out in chemistry, physics or biology. The author of the best report, in the opinion of the judges, will receive a prize of books to the value of £15 and there will be a second prize of books to the value of £10. In addition, books to the value of £15 and £10 will be awarded to the school libraries of the first and second prize winners respectively.

Full details of this competition are available from the publishers of *Research*, 4 and 5 Bell Yard, London, W.C.2.

RESEARCH

The 1960 Waverley Gold Medal Essay Competition

RESEARCH is this year sponsoring The Waverley Gold Medal Essay Competition for the eighth year in succession. The Competition is designed to encourage the scientist in the laboratory and the engineer in the production plant to express his views and translate his work into an essay that will readily be understood by other scientists, directors of industrial firms and others interested in science and technology.

The **Waverley Gold Medal,** named after and bearing the coat of arms of the late Lord Waverley, together with **£100** will be awarded for the best essay of about 3,000 words describing a new scientific project or practical development, giving an outline of the scientific background, the experimental results and the potential application of the project or process in industry. The essays will be judged for technical content by specialists in the subject, for clarity of presentation and for style.

A second prize of **£50** will be awarded and also a special prize of **£50** for the best entry from a competitor under the age of thirty on 31st July 1960. If the first prize is awarded to a competitor under the age of thirty, the special prize will go to the next best entry. For full details write to the Editor of RESEARCH, 4/5 Bell Yard, London, W.C.2.

All entries must be received by the Editor not later than 31st July 1960

RESEARCH IN LONDON'S TECHNICAL COLLEGES

STRACHAN COUSINS

THE biggest backer of research in technical colleges in the London area is the London County Council and it does this in two ways. It provides for the appointment of research assistants in the colleges, and it allows to teaching staff who qualify for it research time which is usually on the basis of three to six hours a week throughout the session. At the first of November 1959 the number of research assistants authorized by the L.C.C. was one hundred and thirty distributed throughout the colleges in this way:

Battersea College of Technology	24
Borough Polytechnic	5
Chelsea College of Science and Technology	24
Northern Polytechnic	20
Regent Street Polytechnic	10
Sir John Cass College	18
Northampton College of Advanced Technology	15
Woolwich Polytechnic	11
Norwood Polytechnic	3

In September, 1955 there were forty four research assistants in these colleges. In 1957 there were fifty eight and by 1958 that figure had risen steeply to one hundred and seven. Now there are fifty accredited to chemistry, eighteen to physics and fourteen to engineering. Mathematics is low on the list, and so, as one would expect, are botany, zoology, physiology and pharmacology. Only one falls within the field of the social sciences, and this is not because the education authority is opposed to research of this kind but because there seems to be little interest shown in the human relations of industry by the colleges.

Not all of the one hundred and thirty assistantships are filled. Most of them are occupied by graduates reading for higher degrees but this is not a stipulation that the L.C.C. insists on. Each assistant appointed under this scheme receives £400 a year normally for two or three years, and in addition he is paid for the six hours a week teaching he is obliged to do in college, a requirement which not only keeps students in touch with research developments but eases the load of teaching that the full time staff have to carry.

There are no figures available to show how much research time has been awarded and is being used by the teaching staff of technical colleges in the London area, but it is believed that its size is remarkable. For example, at the Battersea college a willingness to undertake research is a condition of employment. In other colleges it is encouraged but not enforced. Chelsea which has a long history of research success has many staff spending part of their working week on scientific projects, and so also does the Sir John Cass college. Unfortunately not all staff who are given a research concession are able to use it, as teaching, rightly so, takes first place and pressure of work has been known to keep the allowance in almost permanent abeyance. It is intended by the authorities that research time should be blocked for a morning or afternoon session or in some cases for a whole day but there is no rule about this and it is not unknown for the researcher to find his precious allocation spread uselessly in short periods over several days, for what research can be done in an odd hour between two lecturing periods?

Links with Industry

It was hoped that as the technical colleges developed, and more particularly since the creation of the C.A.T.S., that the links between colleges and industry would become stronger. Research is one of the means whereby this has been brought about. The Northampton college is working with industry on several research projects. Chelsea college has strong connections with industry and research there with industrial collaboration is being undertaken in the School of Pharmacy and in the Department of Physiology and Pharmacology, and both the Chelsea and the Sir John Cass colleges have been helped to develop research by the Medical Research Council.

But the Brunel College of Technology although it comes under the aegis of the Middlesex County Council cannot be left out of a list of London technical colleges. Brunel is very prominent in the research field and has won for itself the kind of prestige in the eyes of industry that few other colleges enjoy. Research at Brunel is shared by teaching staff, research assistants and research students. It has many projects whose pursuit has been made possible by industry. The Ministry of Supply, now the Ministry of Aviation, has sponsored research at Brunel in the Electronics' Department of the college. The Mond Nickel company, the Court of the Salters' Institute, Lautier Fils Limited and the Central Electricity Generating Board are

all financing research at Brunel. Not many technical colleges have applied to the D.S.I.R. for research assistance but Brunel college has and has been given a grant not exceeding £4875 towards the cost of research on Inspection and Quality Control, a project that comes within the Department of Management and Production Engineering.

The Brunel college also enjoys a grant of £15,000 from the Nuffield Foundation to help to establish a centre for Psychological and Social Research with particular reference to problems of technical education and of the human factor in industry. Middlesex County Council is also supporting this venture. The research on technical education is being directed towards the working relationship between industry and college on the sandwich diploma courses where close co-operation between these two, indeed a feeling of co-partnership, is essential to the success of these technological training schemes. Other research stemming from this new centre is on such subjects as attitudes to work, the acquisition of manual skills, and workers' opinions of wage payment systems.

The newer colleges are better equipped for research purposes than the older ones. In one of the latter group the head of an engineering department refuses to countenance research for industry until he has the working space to make it feasible. Staff accommodation in his college is so inadequate that it is impossible for a lecturer to find a quiet corner where he can prepare his lectures or mark students' scripts. Research with industry, that head argues, should proceed on some kind of a time-table the first essential of which is that equipment and working space shall be available at regular intervals.

Research versus Teaching

Staff in technical colleges are not at one on the subject of research. There are those who deplore the Battersea school of thought that decrees that each new member of staff must do research. There are those who suspect that research is usurping the place of teaching as the first function of technical college staff and who feel that where promotion is concerned the former carries more weight than the latter. And there are those, admittedly in a minority, whose research activities go unrecorded and unsponsored because they want it that way and choose not to have a research authority to report to.

Direction of Research

Some facts stand out in this survey of research in the London technical colleges. The first is that it is in the pure sciences where most research is taking place, and it would seem that the long tradition of research in chemistry and in physics has produced a race of teachers in these disciplines who regard research as a natural element of their job. They expect to do research. Slower off the mark are the engineers, builders and mathematicians, yet industry has great need of help from them and would willingly finance acceptable ventures. The technologists, moreover, lack the skill of the pure scientists in making applications for grants for research. A second fact that emerges from this enquiry is that too little attention is directed at what the colleges are doing. Brunel is an exception to this so far as the sandwich diploma courses in technology are concerned. There is room for more of this self examination not only in other colleges but at other levels of work. If there is research going on in technical colleges in the London area into day release schemes or into craft and trade apprenticeships it is not being prosecuted by L.C.C. research assistants, yet in these subjects even short questioning sessions between colleges and industry could well bring about interesting and possibly startling revelations.

Gifts and Grants

A further fact that should be noted is that those colleges co-operating with industry in research are being helped with gifts of equipment and materials by industry. Here again Chelsea is a case in point. During the session 1957–58 (the figures for last session are not yet available) Chelsea college received research materials, museum specimens and student prizes for the pharmacy section alone from more than twenty firms.

And the final significant fact that emerges is that research in technical colleges is not normally triggered off by industry. There are disappointingly few research assistants in the London colleges provided by industry. Indeed were it not for the L.C.C. little research would be being done. The impetus for research must come from the people at the top—from the Governing Body and from the Principal. If the principal wants his college to be active in research then generally speaking, it will be. And if he does not want this then his staff must be content to be pedestrian or take their talents elsewhere. A lively principal will see that he has the right kind of people on his governing body with the proper mixture of the eminent from town and gown and factory. Advisory committees can also be strengtheners as the more distinguished colleges demonstrate. So far as research assistants are concerned the policy of the L.C.C. is to them that ask shall be given. That is why college allocations vary from none to few to many. The request must come from the principal.

STUDIES OF FIRES IN BUILDINGS USING MODELS

Part I. Experiments in Ignition and Fires in Rooms

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Part I of this paper reviews the results so far obtained in experiments to study the ignition, growth, duration and temperature of fires in single compartments. Two types of fire are distinguished; one with relatively low ventilation, burning at a rate proportional to the air flow and the other with a relatively large window area, burning at a rate which increases with the exposed surface area of the fuel. Part II, 'Some Theoretical and Practical Considerations' will be published in the March issue of RESEARCH.

MANY of the building regulations in the United Kingdom relate to fire prevention. Some are based on a sound appraisal of what can and does happen in a fire while others are based on grounds which are more speculative. Economic pressure demands that fire regulations are not too onerous and in the past it has sometimes proved possible to meet the fire requirements in the course of satisfying others such as those relating to the strength of the structure. However the use of new light-weight materials, for example, makes this less likely and satisfying the fire requirements becomes relatively more difficult. For these reasons it is necessary to know more exactly than in the past what factors influence the behaviour of building fires so that building regulations may be based on scientific information.

To meet this need the factors affecting the severity and duration of fires are being studied in various laboratories in the United Kingdom and in other countries.

To study fires experimentally one has mainly to study small fires—any other approach becomes costly in time, money and staff, and to obtain accurate information about a phenomenon as variable as a fire, experiments must be performed and repeated under controlled conditions. In this paper some of the results of laboratory experiments will be outlined, particularly those relating to the study of building fires by means of small-scale models.

Ignition

Fires start by some material becoming ignited and to reduce this risk one must know the conditions required for the ignition of various materials. It is recognized that ignition cannot always be easily prevented and measures must be taken to restrict the spread of fire to other materials. Since the spread of flame may be regarded as essentially a continuous ignition of material, the understanding of ignition, particularly of wood and other cellulosic materials has an important place in fire research.

Later in this paper ignition is also used to illustrate some of the ideas involved in the use of small-scale experiments.

Ignition is a complex process depending on many other processes which are more fundamental, particularly on heat exchange and reaction kinetics. Nevertheless it has been shown that for a wide range of conditions one can regard ignition as occurring when the material involved is raised to a certain temperature, the 'ignition temperature'. Thus, LAWSON and SIMMS[1] showed that the concept of a constant ignition temperature could be applied to the ignition by radiation of wood if the surface was heated to about 500°C in 1 to 20 seconds.

Recently SIMMS[2], MARTIN and LAI[3] and SAUER[4,5] have been able to correlate the times taken for a number of cellulosic materials of differing thermal properties and thickness to ignite spontaneously. *Figure 1* shows SIMMS' experimental results compared with a curve calculated from elementary heat transfer theory.

Very High or Very Low Rates of Heating

There are two regimes for cellulosic materials where the ignition temperature cannot be regarded as a constant for a material and where the chemical factors have to be considered as well as the physical properties.

The first regime is the very rapid heating of materials. The external heating rapidly raises the surface to a high temperature but the penetration

of heat is too small to produce sufficient decomposition products to cause ignition. This regime, in which the ignition temperature depends on the rate of heating, has little relevance to ordinary fires, but may be important in ignition by atomic explosions or by lightning.

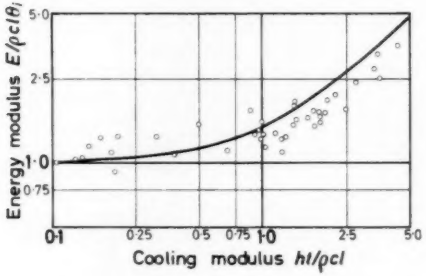

Figure 1. Ignition by radiation (thin cellulosic materials

E—Energy absorbed by material
t—Time of exposure
ρ—Density
c—Specific heat
l—Thickness of material
h—Surface cooling coefficient
θ_i—Ignition temperature above ambient, 525°C
Range of intensities 1–14 cal cm^{-2} s^{-1}
Range of thicknesses 0·02–0·065 cm
Range of times 1–20 s

The second regime concerns very slow heating where in the limit no external heat is supplied once the material is above a relatively low ignition temperature and the material is self heating by exothermic reaction to the point of ignition. Again the ignition temperature is not constant; it is related to the size of the material as well as to its chemical and physical properties. This type of ignition is in its essential features a thermal explosion and the well established theory of thermal explosion[6,7] can be applied.

The theory leads to the defining of a parameter

$$\delta = \frac{\rho Q f w_0^{n-1} r^2 E e^{-E/RT_0}}{\mathbf{R} K T_0^2}$$

where E is the activation energy, Q the heat of reaction per gram of total substance, f the frequency factor, w_0 the volumetric concentration of reactant causing ignition, T_0 the absolute temperature, $\mathbf{R}$ the universal gas constant, n the order of reaction, r the linear size of the material, K the thermal conductivity and ρ the density. The parameter δ is essentially a dimensionless heating rate and the critical condition for ignition or explosion to occur is that δ has a certain numerical value δ_c for a particular shape of material and boundary condition.

Contributions to the application of this thermal explosion theory have been made by several workers[8,9,10]. Although much of the interest in this field concerns the prediction of maximum sizes for safe storage, the study of self heating enables one to obtain values of some of the rate constants for use in the study of the combustion of cellulosic materials.

One of the major differences between the two processes of slow self heating and thermal explosion is that the heat of reaction in an explosion is very high and explosion occurs with only a little loss of reactant. This is not necessarily so for the slow self ignition of cellulosic and similar materials and the effect is to increase the critical numerical value of the explosion (or ignition) parameter δ_c.

It can be shown[11] that for symmetrical heating the effect of reactant loss on δ_c is given approximately by

$$\delta_c(B) = \delta_c(\infty)\,[1 + 2{\cdot}85\,(n/B)^{2/3}],$$

where

$$B = (E/\mathbf{R}\,T_0^2)\,(Q/c)$$

and c is the specific heat.

The general formula is in good agreement with the theoretical numerical data obtained by RICE, ALLEN and CAMPBELL[12] for a first order reaction and gives twice the value for the correction to the value of δ_c that was given by FRANK-KAMENETSKII[13]. For wood fibre insulating board with an activation energy of 23–25,000 cal/g[8,9,10], $c = 0{\cdot}34$ and $Q = 100$ cal/g[10] and δ_c is about 40 per cent higher than if reactant loss is neglected. In these three theoretical analyses allowance is made indirectly

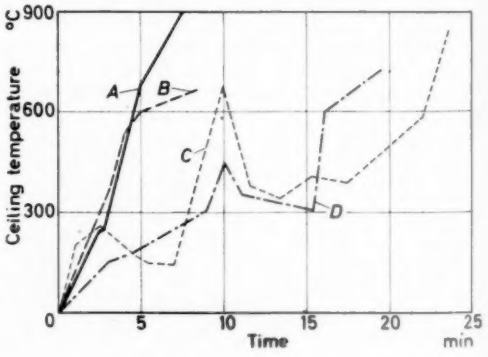

Figure 2. Comparative temperature records of full-scale and model rooms

A—Full-scale room lined with fibre insulating board
B—Model room lined with fibre insulating board
C—Full-scale room lined with plasterboard
D—Model room lined with plasterboard

for the spatial variation of temperature within the solid by an approximation in the differential equation but one expects the result to be satisfactory to a first approximation.

increasing in size from the initial outbreak to involve the whole compartment. The behaviour of the fire once it has filled the compartment is probably easier to study because it is less transient.

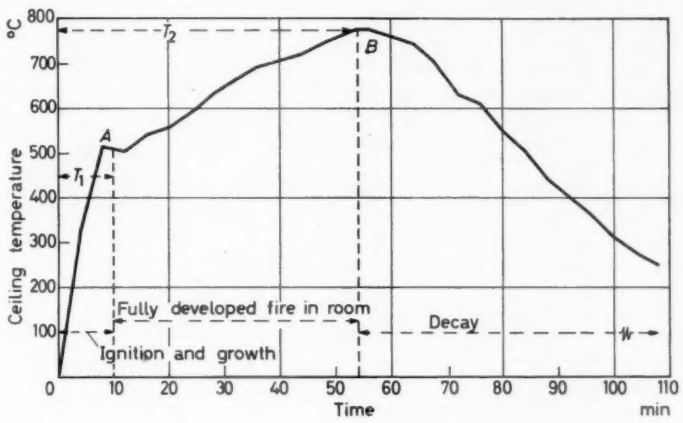

Figure 3. Temperature-time record for a typical fire (small scale)

Ignition Experiments and the Effect of Scale

Clearly from the definition of δ and the fact that ignition just occurs when δ has a fixed numerical value, one can see that scale influences the self-heating behaviour—the larger the value of r, the lower the ignition temperature T_0. The use of a theoretical analysis enables considerable progress to be made in the study of the self-heating problem by means of small-scale experiments. But since the derivation of this theory assumes certain simplifications in the reaction kinetics, the use of small-scale experiments to predict large-scale phenomena must be made with caution. Likewise in the ignition of materials by radiation there are certain secondary effects associated with scale[2]. These are thought to arise from changes in the distribution of temperature and concentration in the plume of volatile products as the size of the irradiated area changes and mainly affect the threshold conditions for ignition with very small specimens. If ignition occurs readily the time taken to ignite is not greatly affected.

Fires in Single Compartments

However in a fire in a compartment the relative importance of the many physical and chemical processes occurring is less well established. This is especially true of the early growth when a fire is

In the following sections of the paper some of the work undertaken by the Joint Fire Research Organization to study the behaviour of fires in rooms will be described. Experiments have been made over a range of scale so that in the first instance an attempt can be made to correlate the behaviour on different scales. As it becomes possible to define the main rate controlling processes—these may well differ for different aspects of the behaviour—so it will, it is hoped, become possible to design models from basic principles to simulate actual building fires.

Growth to ' Flash-Over ' in a Room

A small fire in a room behaves as if it were in the open but will generally spread and become larger and, except in the case of rooms having relatively large windows, and then only if these are open, its further growth will be affected by its being in an enclosure. This is because the enclosure tends to conserve heat and to restrict air supply.

The fire eventually involves the whole compartment—a process which may become very rapid towards the climax, and has been called the ' flash-over '. The amount of fuel consumed in the growth is generally a relatively small part of the total fuel content and in this period there is not much damage, except by smoke, to neighbouring compartments.

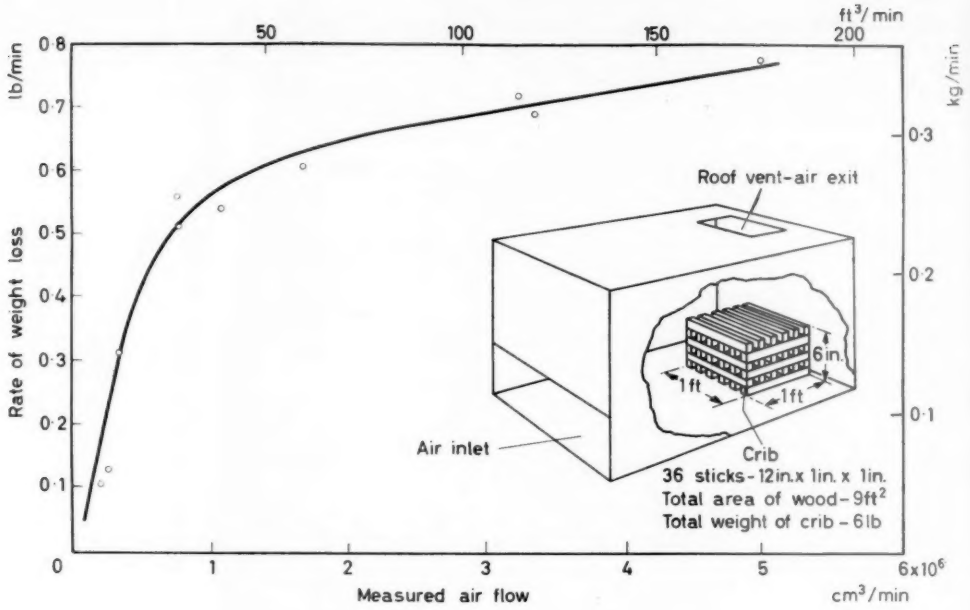

Figure 4. The effect of air flow on burning rate

However this period of the fire is very important from two points of view. Firstly, there is the risk to life because at flash-over the atmosphere in neighbouring compartments becomes lethal, and secondly the quicker the growth of fire the larger the fire is when the fire brigade arrives.

Large and small-scale experiments have been made to study this growth, particularly the effect of different types of wall lining. HIRD and FISCHL[14] showed that the course of development of a fire in a furnished room with a wooden floor with either flammable or incombustible wall linings could be reproduced in model rooms of about one-tenth the linear size of the original.

Figure 2 shows the temperature–time curves obtained in two pairs of experiments on different scales. Despite some considerable variations in temperature between the model and the original the patterns of growth in relation to time are very similar. These results are very encouraging for future work in this field but a fire which is both increasing in intensity and spreading is a complex problem owing to the effects of the disposition of furniture and the many physical processes involved, and the work is still in its early stages.

Nevertheless these experiments have already shown that the *Surface Spread of Flame* test[15] leads to results where undue weight may be given to certain differences between the more flammable linings and insufficient weight to differences between the better wall linings. Because of this, a new test has been developed by HIRD and KARAS[16] and BIGMORE[17] to assess the contribution wall linings make to the growth of fire to flash-over.

Clearly one of the important elements in a study of fire spread, be it inside an enclosure or on an external surface, is the height reached by the flames, because this determines the rate of preheating ahead of the flame and therefore the rate of flame spread. It also determines the radiation transfer to nearby materials. Some experiments are being made to find how flame height varies for different conditions and these are described later in the paper.

Behaviour after Flash-Over

At about the time of flash-over flames emerge from the windows, showing that insufficient air is reaching the fire to burn all the gaseous fuel being produced by decomposition. The fire then burns at an approximately steady rate until the production of volatiles falls and flames no longer emerge from the windows. A typical temperature–time record of a small-scale fire obtained by SIMMS, HIRD and

WRAIGHT[18] is shown in *Figure 3*. The point (*A*) is the flash-over. After flash-over the temperature continues to rise to a maximum at (*B*). In the final period, after (*B*), when the temperature falls because the production of gaseous fuel ceases, some of the residual charcoal may burn to ash.

The structure should be so constructed that it is able to contain the fire and so prevent spread of fire to other compartments. It is first necessary to predict the duration and temperature of fires for a wide range of conditions to determine what is required of various structures and under what conditions to test them.

The immediate considerations are therefore the rate of burning and the temperature and what affects these quantities. There are of course very many variables involved but two which are amongst the most important, if not the most important, are the ventilation (air flow) and the total quantity and disposition of combustible material (fire load). A description now follows of how two types of fire can readily be distinguished according to the amount of air flow.

Effects of Ventilation

The amount of air entering an enclosure with one opening, the enclosure being considered to be at a uniform temperature, has been shown by FUJITA[19] to be approximately proportional to $A\sqrt{H}$ where A is the area and H the height of the opening. This proportionality is not very sensitive to variations in temperature if the temperature is over 600°C. The air flow depends in principle on the ratio of inlet flow of air to the rate of discharge of products of combustion but since the rate of loss in weight of the fire, *i.e.* the mass flow of fuel, is of the order of a fifth of the mass air flow (see below), the effect of small variations in this ratio may be disregarded.

Moreover where there is considerable gaseous motion within the enclosure the pressure differences tend to disappear because the accelerations in the flow occur within the enclosure rather than across the window opening, and as the window opening becomes larger and one obtains a rapidly moving flame zone which only partly fills the enclosure, the air flow may be expected to be determined by turbulent entrainment.

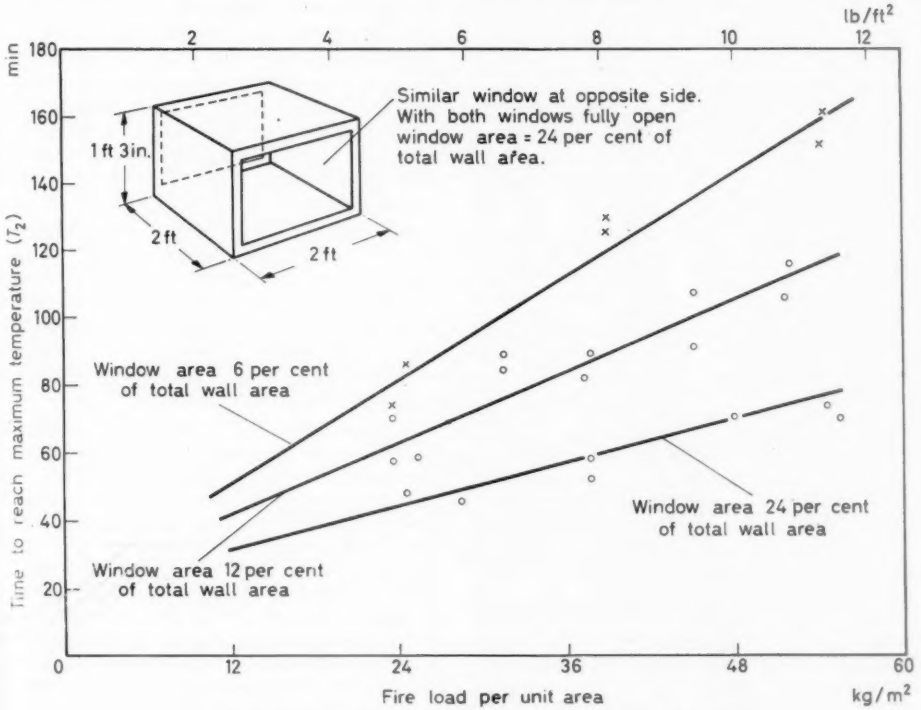

Figure 5. The duration of small scale fires (restricted air flow)

Simms and Hinkley have recently measured the rate of loss of weight of cribs of wood in small-scale enclosures having an opening at low level and sometimes also an opening in the roof. The total air flow was calculated from measured values of the

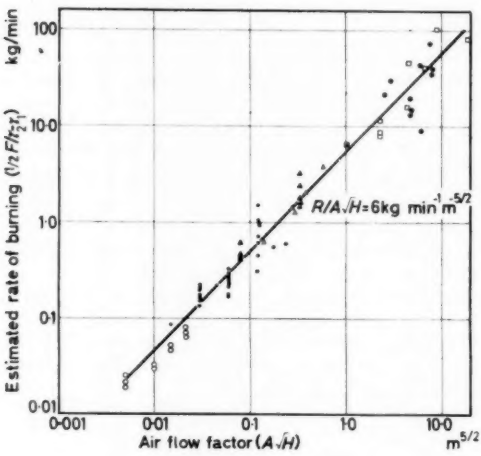

Figure 6. Burning rate and air flow

Key	*Floor area* ft^2	m^2	*Symbol*
HIRD and WRAIGHT	1 4 9	0·093 0·37 0·83	○ • ▲
HIRD and FISCHL	34	3·2	■
KAWAGOE	11 ~100	1·0 ~9	△ □
ASHTON and MALHOTRA	100	9	●

inlet air velocity. The rate of burning was relatively constant over a long period and this value is shown in *Figure 4* plotted against the total air flow. It can be seen that the rate of burning depends markedly on the air flow at low air flows but at high air flows it reaches an almost constant value.

The two sets of conditions will now be dicussed separately in more detail.

Fires with Low Ventilation—Rate of Burning and Duration

In compartments with low ventilation such as are common in traditional buildings, the duration of the middle period T_2–T_1 (see *Figure 3*) is generally long compared with the time to flash-over. *Figure 5* shows the relationship, found by SIMMS, HIRD and WRAIGHT[18] in small-scale experiments, between the time T_2 and the fire load. The time T_1 was approximately constant and was small compared with T_2 so that for a given degree of ventilation there was a mean rate of burning which was largely independent of the fire load.

PTCHELINTZEV[20] has also reported experiments showing the effects of ventilation and fire load on rate of burning. *Figure 6* shows the rate of burning as a function of $A\sqrt{H}$ for KAWAGOE's experiments[21] over a range of scale together with those of SIMMS, HIRD and WRAIGHT[18]. Some recent experimental results obtained by ASHTON and MALHOTRA[22] for full-scale rooms were also plotted on the same figure.

Because in the experiments of Hird and Wraight and of Ashton and Malhotra no direct measurements were made of the loss in weight, a mean burning rate has been calculated from $\frac{1}{2}F/(T_2-T_1)$ where F is the total weight of combustible and the fraction $\frac{1}{2}$ has been assumed for the fraction of wood producing a charred residue, burning largely as charcoal. However for the purpose of comparing data over a wide range of scale this assumption is not critical.

Some of the scatter in the central part of the graph is due to the inclusion of results for fires in which the windows were large in relation to the wall area, where the behaviour of the fire is dependent on the amount and surface area of fire load rather than on the value of $A\sqrt{H}$.

The results given in *Figure 6* show that for compartments of approximately similar shape but varying in volume from about 0·2–300 m³ the rate of burning R for small traditional windows, in relation to the value of $A\sqrt{H}$ does not show any marked scale effect. The mean value of the ratio between R and $A\sqrt{H}$ is about 6 kg min^{-1} m$^{-5/2}$ corresponding to an overall air/fuel ratio of about 5.

The data in *Figure 6* include some results for wood $\frac{1}{2}$ in. as well as 1 in. thick. The greater surface area appears to give some, though not a proportional, increase in burning rates but, generally speaking, the rate of burning is largely independent of the fire load. These results show therefore that for fixed low ventilation conditions the duration of the fire is proportional to the total fire load, not the fire load per unit area. The large-scale tests included in the data shown in *Figure 6* are only full scale in terms of a domestic room, but there is no obvious reason why the same relationship between the rate of burning and air flow should not apply for much larger fires, *e.g.* a single-storey factory.

It is interesting to consider the relationship between the duration of a fire and area for such a building. For a given type of occupancy one may assume that the total fire load is approximately proportional to the total floor area A_{fl} and that the air flow for a given distribution of windows in the walls will be proportional to the perimeter, *i.e.* to $\sqrt{A_{fl}}$, for similarly shaped buildings. The duration of the fire will therefore be proportional to the ratio of these, *i.e.* to $\sqrt{A_{fl}}$, for a given shape. It is interesting to note that the time taken to control large fires by the fire brigade tends to follow the same law though there are other reasons in addition to the above why this should be so[23].

Fires with Low Ventilation—Temperature

As the absolute value of $A\sqrt{H}$ is increased, the rate of burning increases and even when this is relatively the same in terms of floor area for fires of different scale, higher temperatures are obtained on the larger scale. SIMMS, HIRD and WRAIGHT's[18]

The temperatures referred to are mean values during the period of rapid burning. The temperature is in fact not constant but rises during the period *A.B*—*i.e.* from T_1 to T_2 (see *Figure 3*)—in a way which depends mainly on the cooling effect of the walls. As the walls become hotter less heat is lost to the walls and the mean gas temperature also rises. It is possible to calculate the mean gas temperature and its variation with time from the rate of burning if known[24]. The problem of predicting theoretically both the rate of burning and temperature is discussed briefly in Part II of this paper.

Well-Ventilated Fires—Rate of Burning

It has been shown above that, when the window opening becomes large in relation to the size of the room, the rate of burning no longer increases in proportion to $A\sqrt{H}$ but tends to a constant value for a given fire load. This limiting rate is approximately that typical for a fire in the open. The rate of burning for well-ventilated fires increases in proportion to the

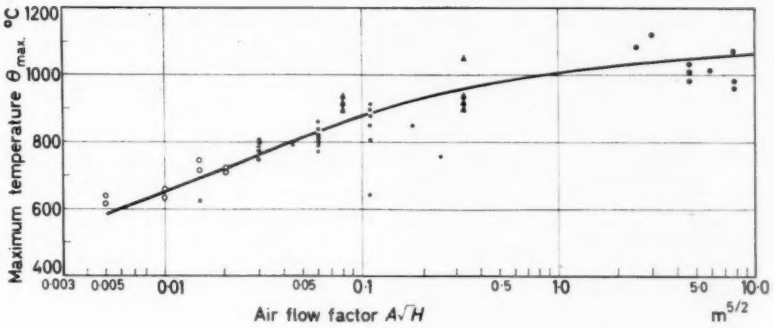

Figure 7. Maximum ceiling temperatures in room fires

Key	*Floor area* ft^2	m^2	*Symbol*
HIRD and WRAIGHT	1	0·093	○
	4	0·37	•
	9	0·83	▲
ASHTON and MALHOTRA	100	9	●

results are shown in *Figure 7*. Results showing the same trend have been attained in several full-scale tests made by KAWAGOE[21]. There is however a systematic difference between the two sets of data, possibly due to different positions for the thermocouples.

fire load, or more correctly, its surface area. *Figure 8* gives some results from WEBSTER and RAFTERY[25] showing this relationship for cribs made of various numbers of 1 in. wood sticks spaced 3 in. apart burning in cubical enclosures with one side open. *Figure 8* gives data for tests in 1, 2 and 3 ft cubes

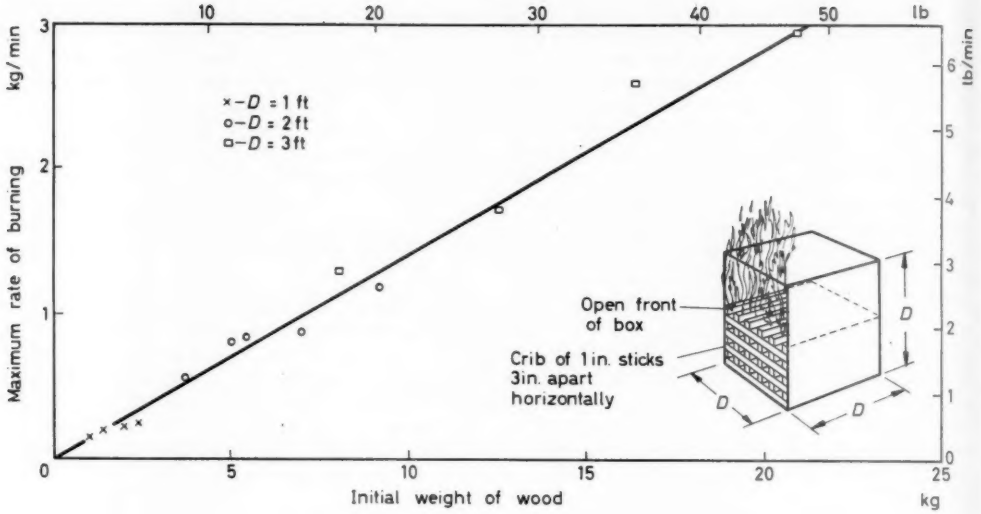

Figure 8. Rate of burning of well ventilated fire

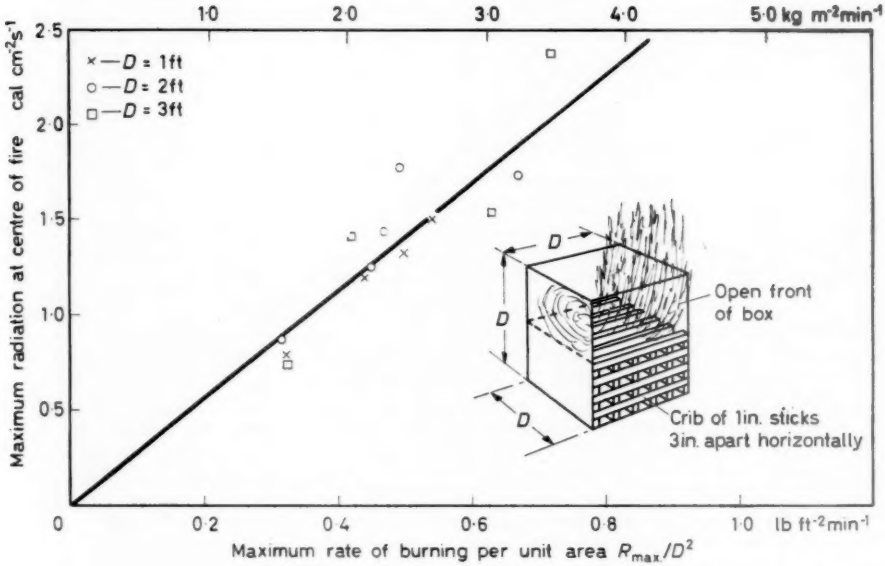

Figure 9. Radiation from opening

and it is especially interesting to note that the same relationship holds between the rate of burning and fire load for all three sizes and hence there is no scale effect in this range. For wood of 1 in. section the rate of burning is relatively constant for a long period, which is partly due to the effect of the increasing temperature of the enclosure opposing the effect of the increased depth of char in reducing the rate of burning. With 2 and 3 in. wood, the rate of burning tends to decrease more markedly with time after an initial maximum rate has been reached. However, for this range of thickness and the relatively large spacing between the sticks that has been used in this work, the maximum burning rate is nearly proportional to the area of wood exposed.

Well-Ventilated Fires—Radiating Temperature

For the fires in cubes, WEBSTER and RAFTERY[25] measured the radiation from the open side; the results are shown in *Figure 9* where it can be seen that all the data have been correlated by reference to the rate of burning per unit area in the range of experiments so far made. Since the floor and window areas were the same and since the burning rate per unit area is almost proportional to the fire load per unit area, it is necessary to perform experiments with differently shaped enclosures before discussing their interpretation.

The work described in this paper forms part of the programme of the Joint Fire Research Organization of the Department of Scientific and Industrial Research and Fire Offices' Committee; the paper is published by permission of the Director of Fire Research. *Crown copyright is reserved on the illustrations.*

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SURVEY

Medical Electronics

The third International Conference on Medical Electronics will be held at Olympia in July next year. The first two, which took place in Paris in 1958 and 1959, were comparatively small affairs with attendances of about 150 and 500 respectively. This third conference is being organized by the Electronics and Communications Section of the Institution of Electrical Engineers in association with the International Federation for Medical Electronics, and an International Medical Electronics Exhibition is being held in conjunction with the conference. The purpose of this combined conference and exhibition is to encourage cooperation between electronic engineers and the medical profession.

There is a great deal of research being carried out on the use of electronic instruments in the medical field. Computers can be used for diagnosis of obscure diseases. In cardiac surgery where the latest major developments have been the use of lowered temperature and of an ' artificial heart ' or cardiac pump whilst the heart is being operated on, it is obviously necessary that very accurate control is kept over such factors as the rate of circulation, pressure in different parts of the body, the oxygen level, pH and temperature of the blood; electronic apparatus is used to check these things. In Germany a small transmitter in the form of a capsule has been devised which is swallowed, and which signals information covering the temperature, pressure and pH of the different parts of the intestine as it passes through. Experiments on this type of apparatus are also being carried out by the Medical Research Council, who have developed a similar capsule 8 mm by 15 mm long.

Checks can also be kept on the respiratory system. The ' pneumotachometer ' measures the volume of air respired at each breath by recording the pressure changes in the trachea and then ' computing ' the volume of air from this. The amount of expired carbon dioxide can be estimated by passing infra red rays through a sample of breath: CO_2 abstracts some of the energy of the rays, the energy loss is measured, and instantaneous recording of the CO_2 content made. Electronic apparatus can be used to check and control machines for assessing breathing, and, by measuring the activity of a patient's brain, for adjusting the rate of delivery of anaesthetics.

Aids for the physically handicapped are also being developed—for the deaf, blind and maimed. Experiments are being made on artificial limbs which can be automatically controlled by electrical impulses from those nerves which would normally have controlled the muscles in the amputated limb, and for sensory ' radar ' perception in artificial limbs. At the conference there is to be a session on ' Electronic Aspects of Sight, Hearing and Locomotion '.

Like the conference, the exhibition is to be international, and it is expected that firms from all over the world will come.

Microtexts

In this country doctoral theses tend to be filed away in libraries and forgotten: only a small proportion are published and therefore made easily available, and a great deal of important work is overlooked.

At a symposium on ' Microtexts as Media for Publication ' at Hatfield Technical College, Mr EUGENE B. POWER of University Microfilms Inc. described how theses are published as microtexts in the United States. For a cost of $20, with an additional $5 if he wants copyright protection, an author can have his thesis filmed. He must provide a 600 word abstract which is included in the journal ' Dissertation Abstracts ', published on a subscription basis, so that anyone who is interested can buy a microfilm or xerox copy of the full-length thesis. The negative of the thesis is filed by University Microfilms Inc., and a positive sent to the Library of Congress. There are ninety participating institutions in America producing 6500 dissertations annually.

It is obviously desirable that a similar scheme should be established in Britain. One of the main difficulties at present seems to be that of cost. Under our copyright laws, as soon as a work is published the five depository libraries can each claim a free copy, and as the overall demand for many of the theses would probably be quite small it would be difficult to recover the cost.

Ultrasonic Welding

The rare metals, niobium, tantalum, zirconium, titanium and various alloys can be fabricated in gauges up to about 0·03 in. by ultrasonic welding*, *i.e.* by the introduction of vibratory energy into the areas to be bonded. The same process can be used for the welding of certain dissimilar materials, metals and alloys, *e.g.* stainless steel and aluminium, nickel and low-carbon steel, and for welding molybdenum, either with or without nickel or platinum foil as a filler metal. There is apparently no significant reduction in the load-carrying capacity resulting from over-all deformation.

* J. B. JONES *Fabrication of Molybdenum* (American Society of Metals) 1959 p. 88

BOOK REVIEWS

Atlas of γ-Ray Spectra from Radiative Capture of Thermal Neutrons

L. V. GROSHEV, U. N. LUTSENKO, A. M. DEMIDOV and V. I. PELEKOV

(198 pp.; 10¼ in. by 8 in.)

London: Pergamon Press. 140*s*

THE Atlas is one of the *International Series of Monographs on Nuclear Energy* and consists of a 2-page introduction followed by 13 pages of tables and 180 pages of graphs of energy and momentum spectra of Compton electrons ejected by capture γ-rays from the chemical elements taken in turn. Adjoining the graphs are smaller tables of γ-ray intensities and γ-transition diagrams.

The main tables give lists of the stable isotopes with their neutron capture cross-sections and abundances, of spins and parities of the ground states of target and product nuclei and of the neutron binding energy in the latter. The binding energy averages about 9 MeV and ranges from 20·6 MeV when the target is He^3 to − 0·96 MeV for He^4. The release of this energy in capture raises the nucleus to a highly excited state and the bulk of the book describes the resulting γ-radiation.

The graphs are restricted to spectra obtained by the authors with their remarkable magnetic Compton spectrometer which is described in the *Proceedings of the 1956 Conference on the Peaceful Uses of Atomic Energy*. Although references to this and other instruments are given in the 2-page introduction, it is perhaps disappointing that no experimental methods are described in the text, in a field in which many ingenious devices have been applied to a difficult experimental problem.

A wide survey of the capture γ-rays has been made in Canada by G. A. BARTHOLOMEW and B. B. KINSEY and their collaborators, using the great neutron flux of the Chalk River reactor. They used a uniform magnetic field pair spectrometer in which a collimated beam of γ-rays ejects positron-electron pairs from a thin metal foil of rather large area. The two members of a pair, ejected in the direction of the γ-ray perpendicular to the field, are bent into two coplanar circular paths clockwise and anticlockwise about the lines of force. For high energies the sum of the diameters of the two circles is proportional to the $h\nu$ of the γ-ray, so that the distance between the positron and electron when they return to the plane of the foil is a measure of the energy and can be determined by a coincidence in two counters placed a known distance apart in that plane. Pairs in which the two members have unequal energies will still have the same sum of diameters and will give a coincidence count if ejected from an appropriate part of the foil. The pair production probability decreases rapidly at low energy, so that the method is of little use below 3 MeV.

A systematic survey of the medium energy region has been made by T. H. BRAID who used a two-crystal Compton scintillation spectrometer of the Hofstadter–McIntyre type. The resolution here is not as good as that given by magnetic spectrometry.

The Russians have used a magnetic Compton spectrometer first developed by Dzhelepov and his collaborators in which coincidences are used in a different way. Compton electrons, ejected from a thin curved target of area 4 × 5 cm within an angle of about 1° of the direction of the γ-rays, are brought by a magnetic field to a line focus, at which their paths cross over. The paths are then deviated through a further 180° to reach a second line focus or image. At each focus is placed the wire of a Geiger counter. The use of coincidences reduces the large back-ground count due to the reactor to about 1 in 30 minutes. This enables very low Compton rates to be counted with accuracy, a very necessary facility in view of the low intensity caused by the need to use a thin Compton emitter to give sharp lines and by the fact that the high degree of collimation of the γ-rays was achieved by having the emitter 16 feet from the γ-ray source.

The treatment of the subject seems to be objective and free from national bias. It is claimed that intensities published in all countries are included up to January 1958. The collection in one book of the graphs of so many spectra is very praiseworthy because it shows at a glance the numerous regions in which unresolved spectral lines are present and in which more work is needed. It would be difficult to get this information from tables which select only the well-resolved lines. The Atlas will therefore be of great value to the specialist, provided that he or his institution can afford the price of £7.

H.O.W.R.

Electrolytic Conductance

R. M. FUOSS and F. ACCASCINA

(ix+279; 9¼ by 6)

New York and London: Interscience Publishers 59*s*, $8

A CONFESSION is made in the preface that a more accurately descriptive title would have read ' Development of the theory of the electrical conductance of dilute solutions of symmetrical electrolytes '. Actually the book is mainly about two things: the Onsager–Fuoss conductance theory, and the effects of ion association upon conductance. The aim has been to present in a continuous and compact form the great theoretical contributions of Onsager and Fuoss, and though this leads at times to a somewhat biased historical view (on p. 8, for example) the resulting book will surely be valued by many physical chemists. It is written in a very readable style, is practically innocent of references, and, in consequence, has no index other than its table of contents. In view of the character of the book, therefore, we are not likely to be too offended by a rather light-hearted approach to matters which lie outside the limits of the main work in hand—as, for example, when in reference to the post-Arrhenius ' anomaly of strong electrolytes ' we find that ' the resolution of this paradox required almost a century '!

Over 200 pages are devoted to the development of the theory which culminated in the most recent papers of Onsager and Fuoss. This section includes separate, short, introductory chapters on the necessary mathematical background (vectors, hydrodynamics, *etc.*), and

will therefore be particularly welcome to the chemist who wishes to follow the growth of a complicated and important theory but finds that his theoretical knowledge is inadequate to enable him to study the original papers with profit. Appreciation of the difficulties of such a reader is evident here, but a statement such as ' Distance is clearly a vector quantity; uphill is obviously the opposite of downhill ' (p.17) may prove discouraging; (is ' displacement ' intended?). A good impression of the achievement of the theory is given by the astonishingly exact fit for the conductances of potassium halides in water up to 0·01–0·02 molar, using values for the distances of closest approach which are almost identical with the sums of the crystallographic radii (p. 203).

The last quarter of the book contains a valuable critique of the theories of ion association. Here we encounter a fashionable idiosyncrasy which may be considered as a recommendation rather than an irritation by many. To the reviewer, however, the danger of confusion between ion-pairs and neutral molecules appears to be grossly exaggerated, so that verbal contortions to avoid the word ' dissociation ' for the former category seem unnecessary. (See pages 191 and 213; but note also a reference to the ' dissociation energy of a pair ' on p. 249!). Regrettably, this obsession has now led to the invention of new jargon, which this book will no doubt do much to disseminate. We have now to get used to ' ionophores ', ' ionogens ', ' pairwise associated ionophores ', and even ' smenocolytic solvents ', though this last seems a bad starter.

P.A.H.W.

Proceedings of the Ninth meeting of the International Committe for Electrochemical Thermodynamics and Kinetics, Paris, 1957

(ix + 489 pp; 10 in. by 6¼ in.)

London: Butterworths Scientific Publications 1959. 120*s*

THIS meeting was held at the same time as the Paris meeting of the International Union of Pure and Applied Chemistry, and the present volume concludes with a summary of a colloquium on electrochemical analysis held jointly with the Analytical Section of the International Union. Otherwise, it follows the pattern of earlier publications in this series, presenting most of the papers read to the meeting, and reports of six of the scientific commissions established by the Committee to consider respectively, Thermodynamic Data, Electrochemical Definitions, Experimental Methods, Batteries and Accumulators, Electrochemical Kinetics, Electrochemistry of Semiconductors.

The first of these is, as usual, concerned with potential–pH diagrams; on this occasion, arsenic, antimony, bismuth, technetium, rhenium, niobium, tantalum, zirconium, boron, aluminium and chlorine have been dealt with. The titles of the rest are largely self-explanatory, and the one of the most general interest is undoubtedly that on electrochemical definitions, presented by P. VAN RYSSELBERGHE in parallel French and English texts. It is a revision and extension of the earlier reports on this topic, and of great value, though naturally not all of it can command immediate and complete agreement. For example, a distinction parallel to that between chemical and electrochemical potential is drawn between 'partial molal chemical enthalpy' and 'partial molal electrochemical enthalpy '. The first two quantities are essential in the consideration of chemical equilibria under conditions of constant temperature and pressure, and the second pair would play a similar role for systems at constant entropy and pressure. Such systems are of academic interest only, and the practical utility of this new distinction is questionable. The function $(H - TS)$ is termed ' free enthalpy ', a more logical and less clumsy title than ' Gibbs free energy ', and it is strongly recommended that the time-honoured ' electromotive force ' should be replaced by ' chemical tension '; this particular change does not seem to have been widely accepted by the authors of papers presented to this meeting. It is to be hoped that the Commission will in future also consider the thorny problem of the best symbols to represent these carefully defined quantities.

The papers themselves vary considerably in quality, and since the best of them could have been published in the normal journals with far less delay, the value of reports such as these can be questioned, particularly by prospective purchasers with limited purses. This is clearly a book for libraries which wish to be strongly represented in the fields of electrochemistry and electrotechnology, and for specialized personal collections. The general form of the book is consistent with the publishers high standards. It has an extensive contents list but lacks both author and subject indexes. Misprints are relatively few but can be irritating in a multi-lingual (English, French, German) publication of this kind.

H.J.V.T.

The Teaching of English

B. C. BROOKES, J. C. CATFORD, W. H. MITTENS, R. QUIRK, J. L. M. TRIM and J. WARBURG

(192 pp; 7½ in. by 5 in.)

London: Secker and Warburg. 12*s* 6*d*

THERE are many complaints that scientists cannot write and some recent complaints that they do not even read! This little volume of less than two hundred pages is the third of a series entitled *Studies in Communication*. It contains, following the introduction, chapters entitled (i) English Language and the Structural Approach; (ii) Some Aspects of Style; (iii) Speech Education; (iv) The Teaching of English in Schools; (v) The Teaching of English to Scientists and Engineers; (vi) The Teaching of English as a Foreign Language. It is written in an interesting, and indeed, in places exciting, style and can be cordially commended.

G.K.T.C.

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